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TESTING MACHINES,

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HISTORY, CONSTRUCTION AND USE.

BY

ARTHUR V. ABBOTT.

REPRINTED FROM VAN NOSTRAND'S MAGAZINE.

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1884.

PREFACE.

For about six years during the construction of the East River Bridge, and for about two years as engineer of the Department of Tests and Experiments of Fairbanks & Co. of New York, the author has been engaged in developing and applying methods of testing the strength of materials. This volume explains such of his most successful methods as seem likely to be generally useful and interesting. A larger and perhaps more useful volume might have been made by extending its scope to embrace untried theories, but he has preferred to limit it to describing methods and machines in actual use.

The volume opens with a brief history of what had been accomplished in this branch of engineering before the author became interested in it. Then follows an exposition of improvements that he has

introduced; chiefly such as embrace automatic contrivances for enabling the machine to do its own recording and adjusting. Lastly is given a collection of instructions for using the testing machine, and a series of tables indicating the correlation between the results obtained from experiments, and processes of manufacture and construction.

The subject is of increasing interest for various reasons: 1st. The enlarging education of practical men is leading them to bestow close attention to it. 2d. Capitalists are looking more closely into the expenditure for materials, with the result that the engineer who builds an adequate structure with less outlay is preferred. 3d. The courts of justice are imposing somewhat heavier responsibilities on proprietors of weak structures. There is a growing disposition in the cases when the fall of a bridge or building, or the explosion of a gas main has destroyed life or injured property, to hold the owner responsible in damages if, by foresight and care in the construc-

tion, the risk could have been avoided. On many accounts the problem of ascertaining the strength of materials to be used in any structure is one of the most interesting of modern practical science.

ARTHUR V. ABBOTT.

NEW YORK, March 6, 1884.

TESTING MACHINES, THEIR HISTORY, CONSTRUCTION AND USE.

HISTORY.

To a celestial visitor, approaching the globe toward the Western Hemisphere, the American Continent would appear like the web of some gigantic arachnid. Long lines of glistening black threads, running from point to point, and here and there converging to a focus, would, on a nearer examination, be decomposed into parallel lines of railway, with accompanying telegraph wires. Spider-like bridges of wood and iron span the rivers, while over the waters, under them, glide all sorts of naval structures, bearing the commerce of a nation. A still closer inspection would decompose the foci of the railways into busy towns and cities, whose substantial buildings, of wood and stone and iron, bear testimony to the truth of the saying, that the prosperity of

a nation may be measured by the success of the people as constructors. Thus, to conquer time and space by joining the two oceans with the railway and the telegraph; to drive a five thousand ton ship across the Atlantic in the face of adverse gales; to erect the structures that now span the Mississippi, the Niagara and the East River; and to dot the continent with buildings, such as may be seen in the streets of any of our cities; would seem to require the most intimate conceivable knowledge of all the properties of all the materials used in construction. Yet such is far from being the case. Indeed the art of construction, perhaps more than all others, is involved in mystery and obscurity; unless the fact that engineers, having arrived at a point where they are ready to say that they do not know, may be credited with having gained a long stride toward perfect knowledge. This unacquaintance with the subject is by no means unaccountable, for a little consideration will show that it is one of the greatest complexity. In designing

an iron bridge, the engineer is at once brought face to face with such a catalogue of operative causes affecting the quality of the material to be used, each one having the power to vary so greatly the iron, that only the keenest foresight, and the most subtle analysis, can predict the result. A slight variation in the ore changing the relative proportion of carbon, phosphorus or sulphur, may give rise to the greatest differences in the refined metal. Changes of manipulation in the rolling mill, apparently slight, such as differences in the temperature at the time of rolling, or variation in the rapidity of the reduction of the rolls, are capable of enhancing or spoiling the value of the product. The knowledge of materials is at present, at least, an absolutely empirical one, for those who are most skilled do not hesitate to admit that any predictions from existing data regarding a new material, or the effects of a new process on an old one, are hazardous in the extreme, and should be received with the greatest caution. "Ex-

perimenta docet" seems to be the only motto for this science. Before the constructor makes use of either a new material, or an old one in a new form, the only safe method is to experiment with the piece in question, carrying the researches far enough to demonstrate all the physical properties, so that the qualifications for the work in question may be accurately known. Thus, and thus only, can the engineer inspire confidence in the structures that he plans, and by a knowledge superior to that of his competitors exhibit such an economy and fitness of design as shall ensure success.

To make experiments on large pieces of iron and steel, having a tenacity of from fifty to one hundred thousand pounds per square inch of section, requires the use of very expensive and ponderous machinery, to which may be attributed the slow progress that has attended investigations of this character. The entire history of tests, and testing machines in this country may be com-

prised within the last thirty years. One of the first machines for making physical tests was designed and built by the late Major Wade, for the United States Government, in 1855 and 1856, and was used in making experiments on the cast iron intended for the ordnance service. A little later this machine was remodeled and improved by Capt. Rodman. Two of the Rodman machines are now in use by the Government, one being in the Washington Navy Yard, and one in the Army Building New York City. These machines consisted of a heavy frame of cast iron carrying three levers, the last and smallest one being used as a scale beam. One end of the specimen (which was turned so as to have two collars on each end) was secured to the iron frame, and the other end to the large lever of the scale system. This whole scale system was then lifted by means of a screw and compound gearing, thus producing stress on the specimen, which was estimated by placing weights on the scale beam. Cotemporaneously, the late John A. Roeb-

ling was engaged in making experiments on the properties of wire at his works in Trenton, and investigating the qualities of rolled iron beams at the works of the New Jersey Iron and Steel Co. A little later Geo. W. Plympton, now Professor of Physical Science in the Brooklyn Polytechnic, made numerous experiments on some full-sized rods designed to be employed in bridges built by Murphy & Whipple. This was one of the first testing machines built to make experiments on full-sized bridge members, and was of unusual dimensions. It consisted of a heavy framework composed of yellow pine timbers 16 ins. by 20 ins., and thirty feet long, set 18 ins. apart, and secured against side springing by pieces of oak. The stresses were applied by a screw, three ins. in diameter, working through a thick iron plate, and one of the oak end pieces. The outer end of the screw was furnished with a rachet wheel 12 ins. in diameter, which worked on the extended screw as a fulcrum. A stout rachet on the lever

completed the movable outside portion on the head of the machine. Inside the head-piece the screw terminated in a stout cast iron cross-head, in which it turned freely. The cross-head carried a pair of parallel flat bars to which the rod under test was made fast. To facilitate the fastening, and to render the machine adjustable for testing rods of different lengths, the parallel bars were furnished with holes 6 ins. apart, and a sliding cross-head that could be attached to the bars by means of pins placed in these holes. At the other end of the machine the stresses were measured by a balance beam 10 ft. long. A heavy iron bolt carried through the head-piece was (after being passed through a thick iron plate which formed the end of the balance beam) forked so as to hold securely a steel block, with a face at right angles to the axis of the rod; this face was made to bear against a knife edge when the machine was in operation. The balance beam was constructed like a king-post truss, with an extra rod following the line of the in-

clined studs. At the end next to the machine the plates above referred to were secured by bolts so as to form the extreme end of the lever. The plate had two blunt knife edges, one on each side; the one toward the machine rested on a plate attached to the oak head-piece; the knife edge on the other side, which was $\frac{1}{10}$ of a foot higher up, had for a bearing, the steel block which received the stress from the rod under test. To the extremity of the balance beam was hung a platform to receive weights. It will be seen that the tensile forces were measured by a bent lever, whose arms were respectively $\frac{1}{10}$ of a ft. and 10 ft. The machine was designed and built by Mr. J. W. Murphy of Philadelphia.

The outbreak of the war diverted the thought of the country to other channels, and little more was heard of testing machines till shortly after its close, when the scale apparatus of a large machine was built for Colt's armory by Fairbanks & Co. This machine is illustrated in Fig. 1, and had a capacity of 100,000 lbs. It has a

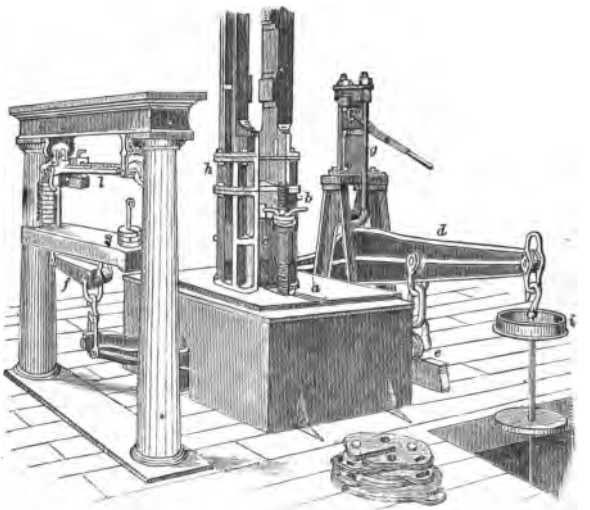


FIG. 1.

platform *a*, with a central opening, through which pass two screws, *b*, entering the cross-head *c*, and connected at their lower ends to two arms of a forked lever below the floor. The long arm of this lever is coupled with the differential levers *d*, *e*, *f*, which act on the scale beam in such a manner that by depressing the free end

of the lever *d*, the cross-head is pulled down. This same effect may be produced by raising the fulcrum of the lever with the hydraulic jack *g*. The machine was fitted with appliances to make test in tension, compression and transverse stress.

This was the first *platform* testing machines ever built.

Another machine was soon built by Fairbanks & Co. for Columbia College, New York. Fig. 2 presents a view of this machine. A large platform supports four heavy timber columns that carry a top cross-head for holding the upper end of the specimen. Through the platform run two screws operating the lower cross-head, and moved by the gearing and hand wheel at the side of the machine. The force produced by the screws, whether in tension, compression or transverse stress, is brought on the platform and estimated by the beam. This machine is fitted with a clockwork attachment for automatically moving out the poise on the beam as fast as the stress increases in the test piece. From

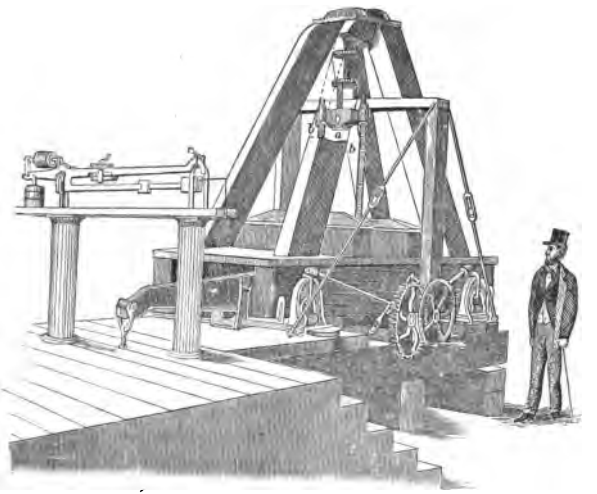


FIG. 2.

these machines as a starting point, Fairbanks & Co. have continued with constant improvements the manufacture of testing machines. Much interest was now manifested in the subject of testing, and the firm of Riehle Bros., of Philadelphia, started in the manufacture of all kinds of machines as regular articles of commerce.

At a convention of the American So-

ciety of Civil Engineers held at Chicago, June 5, 1872, it was, on motion of Gen. Sooy Smith, resolved, that:

Whereas, American engineers are now mainly dependent upon formulæ for the calculation of strength of the different forms of iron and steel not based on experiments upon American materials and manufacture; and, whereas, these differ greatly in many of their characteristics from those of foreign production, both in their nature and form; therefore,

Resolved, that a committee of five be appointed to urge upon the United States Government the importance of a thorough and complete series of tests of American iron and steel, and of the great value of the formulæ to be deduced from such experiments.

Pursuant to this resolution a committee was appointed by whose efforts Congress was induced to pass a law for the appointment of a United States board to test iron and steel, and an appropriation of 75,000 dollars was made for that purpose. This board consisted of Col. T. T.

S. Laidley, Ord. Dept. U. S. A.; Commander L. A. Beardslee, U. S. N.; Lieut-Col. Q. A. Gillmore, U. S. A.; Chief Engineer D. Smith, U.S.N.; Gen. W. Sooy Smith, C. E.; A. L. Holley, C. E., and R. H. Thurston, A. M., C. E., Secretary. One of the first steps of the board was to secure an adequate machine for making the intended tests; for at that time there were no machines in the country capable of making accurate experiments on specimens of more than a square inch of steel. After a thorough investigation of the subject a contract to build a machine having a capacity of 1,000,000 lbs. was awarded to Mr. A. H. Emery, of Chicopee, Mass. During the four years that elapsed prior to the completion of the machine the board did a very large amount of very valuable work in investigating with the Rodman machine, and the large chain-testing machine at the Washington navy yard, the character of wrought iron rods commonly used for chains; and under the direction of Prof. Thurston, at Stevens Institute, the properties of the different bronzes. In

1879 the Emery machine was completed, and the government came into possession of a machine having a capacity of 1,000,000 lbs., and capable of testing specimens (in tension and compression) up to 30 ft. of length. Unfortunately the act incorporating the board limited its life to the duration appropriation of 75,000. With the completion of the testing machine this appropriation was exhausted and the board ceased to exist without having had an opportunity to demonstrate the value of the new testing machine to the community.

At the Centennial Exhibition in 1876, Professor Thurston exhibited a testing machine for making experiments in torsion, which was provided with an apparatus whereby the amount of the stress applied to the specimen and the resulting strain were graphically recorded by the machine on a sheet of cross-section paper. This was the first testing machine arranged to autographically record the results produced by the experiments, and marks a great step in the improvement of such apparatus.

In 1877, in connection with the inspection of the steel intended for the superstructure of the East River bridge, the author of this essay designed, and constructed what is believed to have been the first testing machine for autographically recording the results of the tests made in other than torsional stresses. This machine was not a large one, having only a capacity of 100,000 lbs., and susceptible of experimenting on pieces in tension, compression and transverse strains up to 2 ft. in length, and in shearing to capacity of machine. Briefly described, it consisted of a cast iron base supporting two cast iron columns, on which was placed a differential scale beam. The end of this beam was connected with a swinging weight, so that the stress produced on the specimen caused the end of the beam to rise, swinging the weight through a measurable arc. Connected with the scale beam was a cylinder, carrying a sheet of cross-section paper, over which was mounted a little carriage, sustaining a pencil or stylographic

pen. This carriage was caused to move along the axis of the cylinder by means of a steel tape, connected with the specimen under examination. As fast as the stress was applied to the specimen, the scale beam rose, the cylinder rotated, and caused the pencil to make a mark, parallel to the axis of y, while as fast as the stress produced any deformation in the specimen, the pencil was drawn along the paper parallel to the axis of x. The combination of these two movements gave a curve, whose abscissae and ordinates indicated the amount of stress and strain produced in the specimen.

About two years ago Messrs. Fairbanks & Co. conceived the idea of establishing, in New York City, a physical laboratory completely equipped with testing machines of the most approved pattern, and supplied with such gauges, and instruments for making all kinds of physical investigations, so that engineers, and those interested in construction, could be afforded an ample opportunity to make investi-

gation in any desired direction. The many improvements in testing machines, now to be described, had their origin in the desire of that firm to equip their "Department of Tests and Experiments" so completely that it should be speedily accepted as a standard of scientific accuracy, and should become to America what the laboratory of Kirkaldy has been to England.

Scientifically speaking, a testing machine is a piece of apparatus for the purpose of breaking samples of material, and registering the amount of stress required, as well as the strain produced thereby; and an analytical consideration of the subject divides testing machines into two general classes, namely, machines for special tests and those for general work. Each of these classes may again be subdivided, according to the position that the specimen occupies into horizontal and vertical machines.

With regard to the method of applying the stress, testing machines may be classified as screw or hydraulic machines.

While having reference to the method employed for measuring the stress applied, they may be classed as lever, hydraulic scale or hydraulic gauge machines. These several classes will now be treated in their respective order.

GENERAL TESTING MACHINES.

The machines under this class are those so planned as to make experiments on material in at least three or four different ways, as for example: machines arranged to make tests in tension, compression, transverse stress, and in shearing, bulging, punching and torsion. There are, however, very few machines in the country that aim to make tests in all of the above varieties of stress. Generally speaking, the investigations have been confined to tests made in tension, compression, transverse and shearing stress; while the appliances for torsion, bulging and punching are less frequently added. The classifications into horizontal and vertical machines simply depends upon the position that the specimen has

with reference to the machine. In a vertical testing machine the specimen is placed vertically. Machines of this kind are to be preferred for many considerations, whenever the specimens are not over 5 or 6 feet in length, so as to render this method of construction feasible. In such cases the machine may be built small enough, so as to be placed in an ordinary room, and may be conveniently manipulated from the floor; whereas, when the specimen exceeds the above length, a special building would be necessary; and when large and heavy specimens are to be tested it is exceedingly difficult to handle and place them in the machine with requisite care. Vertical machines may be built of any capacity that may be desired; but of course in making experiments on short specimens it is rarely desirable to carry this capacity above 300,000 or 400,000 lbs. For testing bridge columns, eye-bars, full-sized members of all kinds; angles, channels, etc., a horizontal machine, wherein the specimen may be placed parallel with the floor of

the building, becomes almost a necessity. In a machine of this type the weighing apparatus is generally placed at one end of a long frame-work, designed to carry the reactionary stresses of the machine, while the mechanism for applying the stress, either a powerful hydraulic press or corresponding screws, is placed at the other. Over head, a traveling grip or crane may be conveniently arranged, and by this device specimens of any size or weight, may be readily and conveniently placed in the testing machine, supported during the application of the stress, and the pieces removed as soon as rupture takes place.

The classification according to the method of applying stress into screw or hydraulic machines, simply indicates the method by means of which the force is applied to the specimen. In machines of capacity under 200,000 or 300,000 lbs., intended especially for experimental work, on the qualities of materials, screw apparatus is to be preferred for the following reasons :

First, the screw is absolutely positive. By arranging the driving mechanism, so as to turn the screws either rapidly or slowly, rapidity with which the stress applied to the specimen may be varied at pleasure. As soon as the screws stop turning, the whole apparatus remains absolutely rigid, and the stress may be continued on the specimen for an indefinite length of time. It will be readily seen that this is of especial advantage in the investigations calling the elastic limit and modulus of elasticity into question. For example, should the problem be presented to determine what load a specimen will, for a long time, sustain without detriment, the piece may be placed in the testing machine, the screws turned until the requisite load is indicated on the beam, and the poise left, with positive assurance that unless the machine is wilfully touched from the exterior there can be no yielding or springing from its position, and the load on the piece will not be in any way changed. Again, the method of applying stress by

means of the screw is perfectly uniform and steady, provided that the gearing, driven by the engine or other motor, be run in a steady manner. The piece is, therefore, never subjected to any shocks or jerks or to any variation in the steady increase of the stress. The screw, however, is liable to some disadvantages, for example, the co-efficient of friction is so large that even in the best built testing machines, on this plan, an efficiency of more than ten per cent. is scarcely, if ever, realized. Again, in order to obtain the requisite speed for making tests rapidly, it is necessary to drive the auxiliary gear very fast, so that the screws may be rotated with sufficient speed.

For machines of more than 200,000 or 300,000 lbs. capacity, especially those designed for making experiments on full-sized members, where extreme accuracy of the testing machine is not so rigidly required, hydraulic power is far preferable. By means of a hydraulic press, and an accumulator, or three piston pumps, for continuously supplying fluid

under a maximum pressure, stress up to any desired capacity may be readily and easily applied, as rapidly as may be wished. By means of an accumulator, the fluid forced in the jack may be maintained under a continuous and uniform pressure, so long as the accumulator will run. This piece of apparatus is, however, extremely bulky, if it be designed to supply fluid to a large or highly strained press. By means of a three-piston pump, the fluid may be supplied to the press with almost as steady a flow as that obtained from the accumulator, and of course by supplying a sufficient quantity of fluid to the pump that piece of apparatus may be made to work continuously so that a jack of any length of stroke may be operated without bulky machinery. Testing machines operated by hydraulic power have the advantage of extreme rapidity of action. For example, in making many thousands of tests for the East River bridge, conducted by the author, at the Cambria Iron Co.'s works, in Johnstown, it was customary to break a bar of steel an inch square

and 1 foot long, stretching some 3 or 4 inches in from 6 to 10 minutes; a rapidity which it would be hardly possible to equal in a machine worked by screw power. There is, however, a serious disadvantage in the hydraulic testing machine, from the fact that the pressure is constantly varying, even with the best regulated pieces of apparatus. If it is wished for a moment to stop the action of the pump, either to take a reading on the stretch gauge, or for any other purpose, the beam drops almost immediately, showing that even the pistons of the best packed jacks do leak quite appreciably, and allow the stress to be relieved, unless some means is arranged for retaining a constant pressure on the fluid. Of course, in machines so constructed, it is impossible to ascertain the effect of a long continued stress, unless some means of clamping, or securing the piston rod can be arranged, to prevent this release of stress by leakage around the piston. The co-efficients of friction in the hydraulic machines are comparatively slight,

so that in well-built machines of this class it is possible, as has been demonstrated by numerous experiments, to obtain an efficiency in the machine from 30 to 50 per cent. However, the constant leakage of fluids, around the joints or packings in various parts of the apparatus, gives rise to continued annoyance, and is apt to render the test room a dirty and disagreeable place.

The most important classification of testing machines is, that involving the apparatus for estimating the amount of stress to which the specimen has been subjected. The older machines of large capacity were generally arranged to have a fixed cross-head at one end of the framework, to which one end of the specimen was attached, while the hydraulic press for applying the stress was furnished with some form of gauge for estimating the amount of fluid pressure per square inch, to which the ram of the jack was subjected. By knowing the area of the piston, a simple example in multiplication gave the amount of stress to which

the ram was subjected, and deducting therefrom an estimated quantity for friction, the result was assumed to be the stress to which the specimen was subjected. This, it has been recognized, was an exceedingly crude and only approximate method of obtaining that stress. The co-efficients of friction in the jack are exceedingly variable quantities. If the interior of the jack is smooth and well polished, if the packings have been in for a long time; and have become fitted to the cylinder, and are working at that part that has been most frequently used; if the jack is driven at a comparatively low rate of speed, and if the fluid is a good lubricator and free from grit and from any foreign substance, the co-efficient of friction may fall as low as $\frac{1}{2}$ or $\frac{1}{4}$ per cent. of the entire force exercised by the fluid. But if the interior be rough, the packings, new or working, in a part of the cylinder not often used, the co-efficients may rise to the extraordinary amount of 40 per cent. of the entire pressure placed on the ram.

If this co-efficient of friction were a constant quantity and susceptible of being determined once for all, it would oppose no serious obstacle to the accuracy of the testing machine. But, unfortunately new packings and new supplies of fluid are necessary, and varying conditions of the same are essential, consequently this co-efficient is constantly changing, and may give rise to results on one day that are totally different from those on the succeeding one, so that no machine depending solely and entirely on the registration given by a gauge, of the hydraulic pressure of the fluid can be accepted as giving results that are constantly reliable and accurate. As an example of this may be mentioned the following experiment: A ram having an area of 90 square inches, was on one day worked at a pressure of 1,000 lbs. to the square inch, giving an effect on the scale placed at the other end of the testing machine of only 50,000 lbs., whereas, according to gauge pressure, there should have been a result of 90,000. On the day succeeding the

experiment detailed above, and without there having been any change in any of the parts of the jack, a gauge pressure of 1,000 lbs. gave a scale reading of 85,000 lbs. What was the cause of difference has been an unsolved problem.

The next most common method of estimating stress is by means of the lever or combination of levers. In machines of this class the straining apparatus is so arranged as to be attached to one end of the specimen, while the other end is held in a cross-head directly attached to the levers forming the weighing apparatus. The following examples from some of the most prominent testing-machine makers in the country may be selected as exponents of this system of estimation:

Fig. 3 represents a 100,000 lbs. testing machine, built by J. L. Gill, of Pittsburgh. The machine consists of a heavy cast iron frame-work, supporting the driving mechanism, consisting of some gears and band wheel, seen at the right hand, which are arranged to drive a powerful screw directly at the left of the

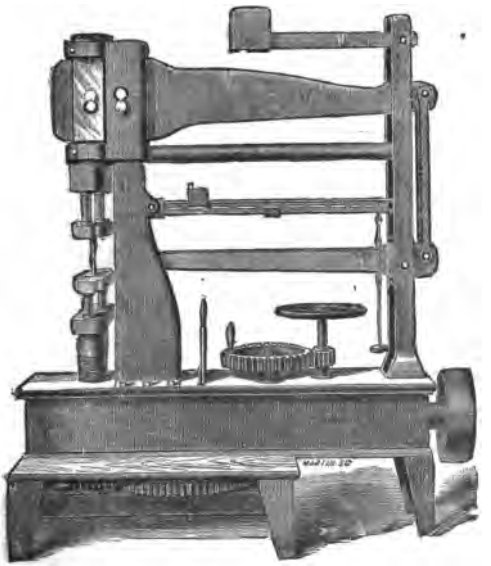


FIG. 3.

machine. This screw carries a cross-head to which one end of the specimen may be attached, while directly over it may be seen a second cross-head suspended from the large lever on the top of the machine. This lever connects, by a link at the left

hand, with a secondary lever directly over the band wheel, which in turn is connected to the third lever, carrying two small poises and a weight counterpoise. The stress applied by the screws and the gears to the specimen is transmitted through it to the upper cross-head, then, acting on the poises and second levers, it causes the third, which is graduated as a beam, to rise. By sliding the poise in and out, and by adding weights to the weight counterpoise, the exact weight or stress applied may be readily ascertained.

In. Fig. 4 may be seen a very compact form of testing machine, built by Olsen & Co., of Philadelphia. Here one of the cross-heads of the machine, to which one end of the specimen is attached is supported on a large cast iron plate by means of four columns. This iron plate rests on the bearings of a large lever seen directly under the frame-work of the machine, which in turn transmits its stress to the beam at the right hand, where, in a similar manner to the previously described machine, the weight may be estimated by

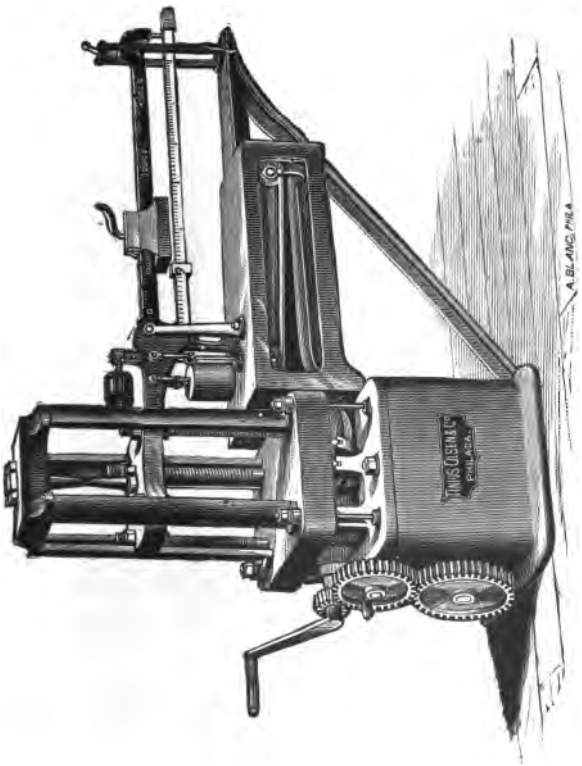
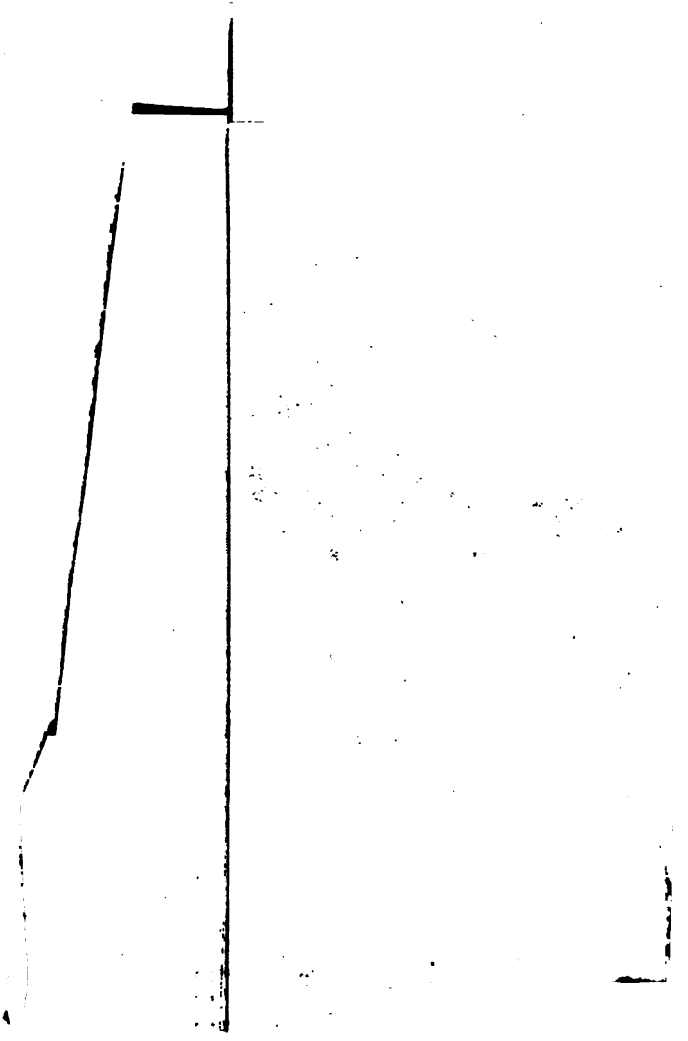


FIG. 4.

tion of the system employed by Messrs. Fairbanks & Co. A heavy frame-work of I-beams is arranged to carry the straining screws with their driving mechanism, and to support a scale system consisting of 8 levers. Four levers are arranged so as to support quite a large platform. From the ends of these 4 main levers, (technically so-called) the stress is conveyed to the central lever C, extending beneath the platform. From the end of this lever the stress passes to two multiplying levers, simply used for the purpose of reducing the amount of stress that is transmitted to the weighing beam. From the end of the last of these multiplying levers, the stress runs directly to the beam and may be estimated by the poises in the customary manner. On the top of the platform there stand two columns, supporting on their tops a large cross-head, to which one end of the specimen may be attached.

In the preceding machines it will be clearly noted that the straining mechanism has no connection at all with that

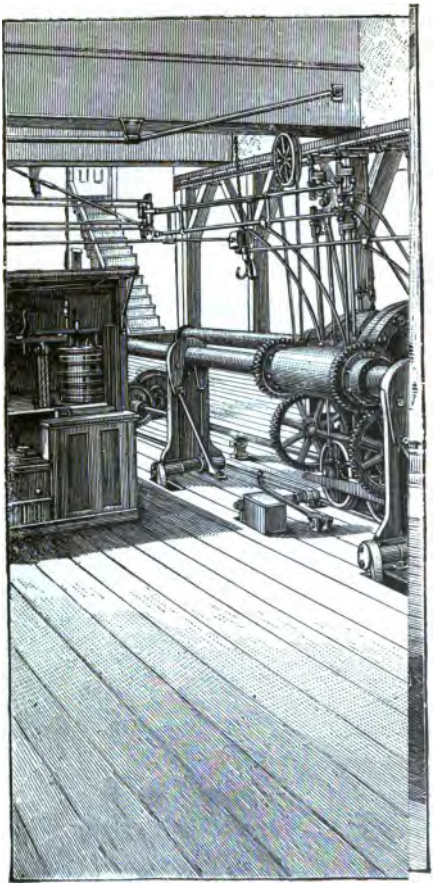


part of the apparatus used for estimating the stress, except such as exists through the piece itself—the specimen forming the only connection between the weighing apparatus and that for producing the stress—consequently, it is obvious that only the stress which affects the piece can by any means (if the testing machine is properly built) produce an effect on the scale beam. Thus it will be seen that all co-efficients of friction, excepting such as may be involved in the levers and pivots themselves, is entirely eliminated from the testing machine, and only the stress used for rupturing the specimen is ever indicated.

The remaining class of testing machines, viz., those that estimate the force applied to the specimen by a hydraulic scale, has but a single representative—that of the famous Emery testing machine.

Fig. 7 gives representation of the machine now at the Watertown Arsenal. Here it may be seen that at one end there is an exceedingly large and heavy-weigh-

ing mechanism, from whence proceed two screws extending nearly the whole length of the room and carrying on them the hydraulic straining jack with the jaws for holding the specimen. Essentially, the weighing mechanism consists of a large receptacle called a hydraulic support, covered with thin flexible diaphragms. This receptacle is filled with a fluid made of a mixture of alcohol and glycerine, and connected to a similar receptacle of much smaller dimensions, placed under the weighing beam. According to the elementary principle of hydrostatics, the total pressure on a surface is proportional to the pressure per square inch and the area of the surface. If, consequently, it be supposed that in the main hydraulic support there is an area of one thousand square inches, and if in a similar miniature hydraulic support under the beam end, there is an area of only 1 square inch, a thousand pounds on the main support will only produce 1 lb. under the beam. It will thus be seen that by varying the relative



sizes of the two hydraulic supports any desired multiplication may be obtained under the beam. The weighing beam, instead of being supported on the customary knife edges, is hung by one or more metal strips. This arrangement will be seen to constitute an absolutely *frictionless* piece of mechanism, for the pressure coming on the large diaphgram is transmitted by the fluid column to the weighing beam, and simply operates to slightly bend the metal constituting the diaphragm and the suspending strips of the scale beam. Thus, in the true sense of the word, the weighing is affected by no friction whatsoever, the only opposing force being the *molecular* resistance to flexure of the diaphragms and the suspending strips. The great merit of this ingenious device is its extreme sensibility, the enormous machine at the Watertown Arsenal being perfectly sensitive to the application of a few ounces of stress between the cross-heads.

QUALIFICATIONS OF TESTING MACHINES.

A testing machine should possess the following qualifications:

FIRST, ACCURACY.—The accuracy of a testing machine should be commensurate with the work that it is required to perform. A testing machine used for breaking bridge bars would not need that accuracy or sensitiveness which would be necessary in a contrivance designed to test silk thread.

SECOND, THE CAPABILITY OF BEING TESTED.—Even the most perfect mechanical contrivances are liable to derangement, and the testing machine, used for heavy work, constantly being subjected to the most severe shocks, its parts being strained to an amount exceeding that provided for in the original design, is especially liable to get out of order. Obviously, a machine so designed as to be tested with ease and facility is exceedingly desirable.

THIRD, A DESIGN EMBRACING A READY ADAPTABILITY TO VARIOUS SHAPES AND

Sizes of Specimens.—In the miscellaneous practice of making experiments on various kinds of material in various stresses, it becomes exceedingly important to a rapid and economical use of the testing machine that it may be readily changed from tension to compression, from compression to torsion, from torsion to transverse stress, and that it should be so planned as to take in a long or short specimen with equal facility.

Fourth, a Rapid Means of Manipulation.—The method of applying the stress, of adjusting the specimen in the machine, and of arranging the various parts, one with reference to another, should be so designed that even in the largest machines all the manipulation that is necessary to making a test itself can be accomplished by a single skilled operator.

Fifth, Self-recording Devices.—As far as is possible in mechanical construction, the machine should be so planned as to make its own record. The advantages of this may be readily seen in the fact that

it prevents the possibility of mistakes on the part of the operator, who, even with the most perfect machines, has so much to do in watching the behavior of the specimen during the test, in regulating the rapidity and direction of application of the stress, as to render it expedient to make the machine itself record, as far as possible, all the important facts that are developed by the experiment. In the light of the foregoing qualifications a number of machines may be now considered.

The Gill machine may be regarded as an exceedingly compact and in many respects desirable form of testing machine for investigating the qualities of specimens of materials. The machine occupies comparatively little room. It may be readily manipulated by means of a hand wheel and belt for communicating power to the screw. The two cross-heads of the machine are accurately bored after all parts of the machine are set up. As a consequence of this, the axis of the machine coincides almost exactly with the

axis of stress applied by the machine, and if the specimen to be tested be carefully turned or planed from end to end, and if exceeding care be exercised in setting the piece in the jaws so that the center of the piece shall agree with the center of the testing machine, it is probable that the axis of stress will nearly or quite coincide with the axis of the piece. The stress produced on the specimen is estimated by the system of levers placed above it. There is, however, no method of testing the accuracy of the machine, except by calculating the ratios of the levers or by taking the machine apart and testing each lever separately, and when first built there is no doubt of a reasonable amount of accuracy. Still there being no method of testing the co-efficients of friction of the levers in their actual place, and no method of ascertaining how accurately the entire apparatus weighs, there would arise in minds at least some question as to the results. The Gill machine is simply arranged for tension and requires additional appliances occupying some

considerable time in attaching and adjusting to enable it to operate in compression, while the other stresses, such as shearing, bulging, punching, torsion and the like require special appliances not furnished with the machine.

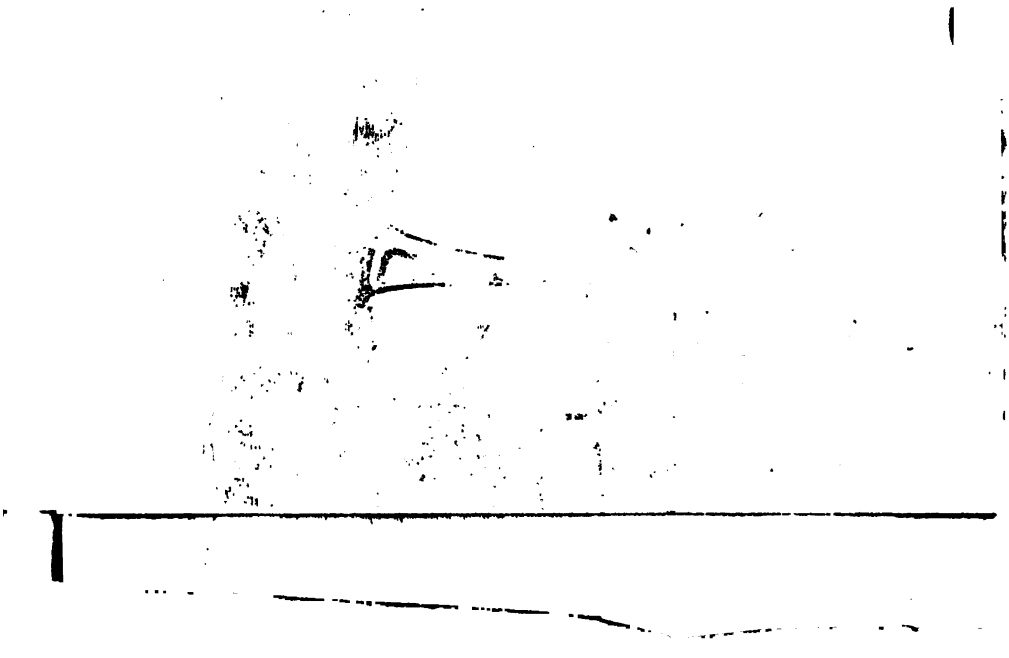
The Olsen machine possesses some points of advantage over the Gill. Here the stress is transmitted through the specimen to the small platform mounted on a different lever contained underneath. By removing the columns, and the crossheads with the screws from the machine, weights to any amount may be piled on the platform by placing thereon a support large enough to contain them. By this means it is possible to test the accuracy of the machine. The use of the differential lever may, however, be somewhat criticised as being liable to a much greater variation in accuracy than the ordinary simple lever system. Here the change from tension to compression is comparatively easily made, for all that is necessary is to place the specimen under the cross-head instead of on the top of it.

The change to transverse, shearing and torsion specimens is made with considerable difficulty. In fact the transverse specimens of any great length are with difficulty accommodated.

In the Riehle machine, tension and compression specimens are easily arranged, but like the Gill machine there are no facilities for testing the machine itself, and reliance must be placed on the accuracy and the care of the makers.

The Emery machine exemplifies one of the best possible contrivances for rapidly changing from tension to compression. Here the hydraulic support is so arranged as to weigh equally as well on either side of it. The jack is sustained on the adjusting screws of the machine by two large bronze nuts, so that all that is necessary to do to change from tension to compression is to reverse the direction of the fluid in the jack so as to cause it to pass from the front to the back of the piston. The method of providing for different lengths of specimens is exceedingly rapid. Along the bottom of the

machine there passes a driving shaft connecting with a system of gear work for turning the bronze nuts. By simply starting the belt for communicating power to the shaft, these nuts may be turned either backward or forward at pleasure, and the jack in a short time adjusted to any different length of specimen. The machine, however, has no appliances for making tests in other stresses than those of tension and compression. Being a horizontal machine, it is not susceptible of an easy test. In order to ascertain whether the accuracy of the machine is maintained, it is necessary to take the weighing end of the machine apart, turn the hydraulic support from its seat, and build a platform to contain the necessary amount of standard weights. While there is every presumption that the Emery machine, having been once carefully and accurately standarized, wil for a long time retain this accuracy, there will arise in the minds of those subject to accurate scientific considerations, that the change in the molecular constitution



of the diaphgram and of the suspended metallic strips, may sooner or later introduce some (be it very slight) error in the accuracy of this contrivance, so that without some easy method of frequent standardization, the results of the machine are liable to criticism. The only method of insuring the coincidents of the axis of stress and the axis of the specimen is by carefully measuring and centering the piece with reference to the axis of the machine, and in one built on so large a scale as that at the Watertown Arsenal, much more time may be consumed in this process of centering than in any other part of the test.

In Fig. 8 a large machine on the Fairbanks' system may be seen, which has recently been constructed with a view to improve on previous machines, and to fulfill the foregoing conditions as far as possible. The lower part of the machine consists of a frame-work of wrought-iron I-beams, standing on two heavy cast iron legs. This frame-work of I-beams supports in the center two screws that may be ro-

tated by the belt or a gearing shown at the left hand. These screws rise in the center of the testing machine and carry the lower cross-head to which one end of the specimen to be examined is attached. Just outside these screws stand a second pair of screws, carrying a top cross-head for the reception of the other end of the test piece. These screws are suspended from a large casting supported on four columns that stand on a second frame-work of I-beams that form a platform of the machine. This large platform some 4 ft. by 10 ft. stands on four levers in a manner similar to that described in the previous testing machine of this system. These levers transfer their stress to two central levers, whence it runs to a couple of multiplying levers, shown in the front of the machine, and then directly to the scale beam. Just in front of the testing machine, standing over the first one of the multiplying levers, may be seen a small frame-work composed of iron columns, carrying on its top a hand wheel and lever. This is an auxiliary testing

machine adapted to making tests on small specimens. The large machine has a capacity of 200,000 lbs., and is adapted to take in tension specimens up to 8 ft. in length, transverse specimens to 10 ft., compression specimens to 4 ft., and specimens in sheering, bulging, punching and torsion to the 200,000 lbs. capacity, the smallest reading on the beam being 10 lbs. The auxiliary machine is adapted to making tests in tension and compression up to 2 ft. in length, and has a capacity of 10,000 lbs., and reads to $\frac{1}{2}$ lb. Thus it will be seen that the apparatus is susceptible of doing work of all kinds up to its maximum capacity. Should a specimen of wire be presented, it may be tested in the auxiliary part of the apparatus to a half-pound, rapidly and easily, while if the next specimen be a 15-in. I-bar, 10 ft. in length, it may be placed on transverse blocks of the large machine and broken in a few moments. The general features of the machine being here illustrated, a more complete idea may be obtained by reference to the following cross-sections:

the first one being taken longitudinally through the center of the machine, and the second transversely through the main levers of the scale system. The cast iron legs supporting the platform will be seen here in side elevation and in cross-section, the main levers *c* and *c* hang from the ends of these I-beams, supported by two cast iron blocks placed over the swinging bearing pivots from the loops suspended by pins placed through these blocks. The ends of these main levers may be seen to be attached to the two center levers *e* and *e'*, whereby the stress is conveyed to the end of the testing machine, and to the two multiplying levers previously alluded to, and thence to the weighing beam. Directly under the I-beams, supporting the scale may be seen a secondary framework, carrying the screws with their appropriate worm-gears. By means of the main shaft *l*, with its system of gearing, the worms meshing into the worm-gears at the base of the screws may be rotated. The power is derived from the belt *l*^{s},

wch derives a counter shaft set directly over the main shaft *l*. By means of the gears on the shaft, several different speeds may be obtained according to the judgment of the operator as he may deem it best to apply the stress to the specimen rapidly or slowly. Directly at the right of these multiplying gears is a system of reverse gears very similar to those employed in a large engine lathe. A lever at the side of the testing machine enables the operator at pleasure to reverse the direction of rotation of the main screws. The worm-gears and main screws are cut respectively right and left-handed, so that the friction of one neutralizes that produced by the other, and all tendency on the part of the piece to twist or get out of order is thereby avoided. On the pivot *c* of the main levers there stand two castings b^2. These support frame-work of I-beams b^3 that forms the platform of the testing machine. On these I-beams stand a second set of beams, *c'*, and also the columns *j* and *j* that support the castings

from which hang the adjusting screws H. The object of these secondary screws is to form a means of rapidly and conveniently adjusting the machine to all the lengths of specimens. For example, the piece in the machine may be 8 or 10 in. in length. At the completion of the test on this piece a bar 5 or 8 ft. will be the next in order. To make the main screws long enough to accommodate such a variety of length of specimens, would require them to be made too heavy, in order to insure sufficient stiffness for preventing lateral vibration. By means of the crank and bevel gears on the upper cross-head, this part of the machine can be rapidly raised and lowered so as to make the different adjustments with great speed. As the upper cross-head hangs on the screws H, they are always subjected to tension, and the compressive reaction comes on the platform by means of the columns *j* and *j*.

In this machine, while strict attention is paid to the relative centering of the cross-heads, there is a device to make the

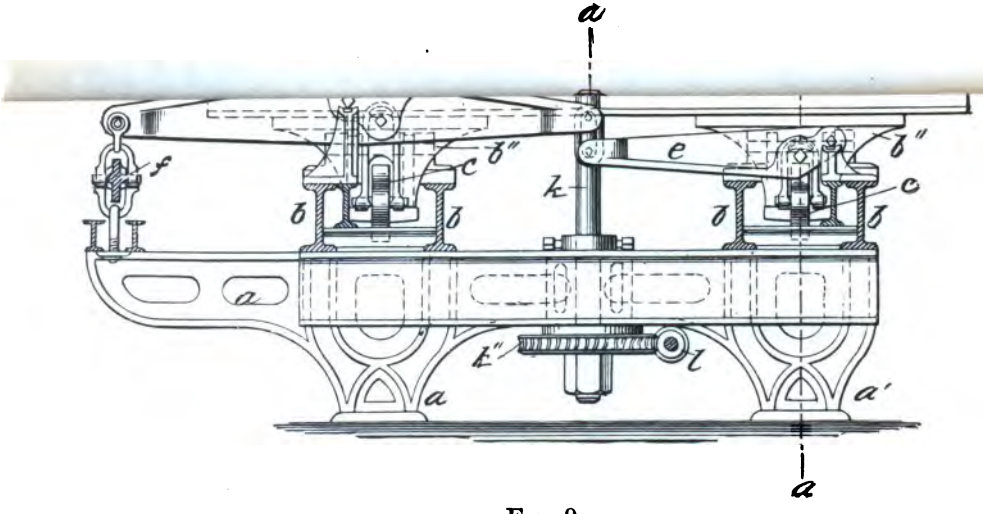


FIG. 9.

testing machine automatically self-centering, so that any possible error in the setting of the specimen or in the alignment of the machine may be corrected by the apparatus itself. It will be noted that the cross heads *b* and *c* are extremely large and are provided in the center with a spherical socket. In this socket there stands a segment of a sphere, carrying the wedges for gripping the test piece.

Let it be supposed that the specimen is placed in the machine eccentrically. As soon as any application of stress occurs the piece swings, and moving the spherical segments in their sockets, adjusts them so as to render the axis of stress coincident with the axis of the piece. The spherical sockets are lined with an anti-friction metal, and the spherical segments are of polished steel constantly lubricated. As a result, the coefficient of friction falls as low as about 5 per cent., and the weight of the segments being less than 200 lbs., the total cross stress that could come on any piece

previous to the movement of the segment is about 10 lbs. Inasmuch as the specimens to be tested in these machines will always rise nearly to 100,000 lbs., this possible cross strain of 10 lbs. can be regarded as an error not large enough to take into account. The facility with which tests in other stresses may be made can be readily understood from the examples in compressive and transverse stress. The two anvil blocks 40 slide on the screws 42, and then the I-beams A may be readily and quickly run in and out by means of the crank 43, so as to adapt the testing machine to any length of span either equal or unequal from the center of the cross-heads. On the top of the anvil blocks the piece for transverse examination is placed, resting on the jaws 44, which are semi-cylindrical pieces of hardened tool steel. The object of these jaws is to facilitate the deflection of the test piece under stress. Right under the cross-head *c* a triangular nose iron is placed, which, by the action of the cross-head, is depressed and brought on

the top of the transverse specimen. As fast as the piece deflects the jaws 44 swing in their sockets and adjust themselves to the constantly increasing deflection of the piece, swinging around their centers and so preserving a uniform length of span, while a broad bearing is constantly maintained under the test piece, and any tendency to cut its edges is thereby avoided. Simply removing the transverse specimen, a compression test may be made by placing under the cross-head *c* a heavy iron plate for the reception of the specimen, and continuing the downward motion of the cross-head. It will thus be seen that the changes from long to short specimens, and from one kind of stress to another may be readily and easily made in this form of testing machines, requiring only manipulation enough simply to introduce the piece to be tested in its appropriate place, while the machine itself is constantly ready for any of the different forms of stress. The same may be said of the appliances for

shearing, bulging, punching, torsion and the like.

The platform of the machine, as has already been stated, has considerable size, and when the machine is built each lever is sealed separately, that is, the lever is hung up from its fulcrum, and standard weights are placed on the pivots, and the distance between the edges slightly varied until these weights exactly balance each other. After the machine is erected in place, standard weights are piled on the platform, and every graduation on the beam is adjusted to the weights previously placed on the platform. It is obvious that the accuracy of the machine is not dependent on the calculation of lever ratios, or on any alteration in the parts of the testing machine, but inasmuch as the platform gives sufficient size on which to place any desired number of standard weights, the machine can at any time easily and inexpensively be proved to be either right or wrong; in fact the weighing of oneself on the testing machine by simply

stepping on the platform is a simple, accurate, and very expeditious mode of making an examination of this kind. Regarding the sensitiveness and the accuracy of the lever system of testing machines, the following experiments may be quoted as derived from actual practice:

A machine, similar to the one illustrated in Fig. 8, has been constantly in use in the "Department of Tests and Experiments" for the past two years. The following experiment was made within a month: When the machine was entirely unloaded, weight of $\frac{3}{4}$ lb. of the platform caused the beam to rise promptly. A test piece was then introduced into the machine, and 100,000 lbs. placed on the platform, when a weight of 6 lbs. caused the beam to move equally with the original $\frac{3}{4}$ lb. Inasmuch as this machine has been subjected to the wear and tear of all sorts of tests, it may be considered that a weight of 6 or 7 lbs. is probably its maximum error, even under the most severe loads. The least reading on the poise of the beam in question is 10 lbs. so that

its sensitiveness and accuracy are within about 60 per cent. of the least reading on the beam; consequently if all coefficients of friction and inaccuracies of mechanical construction are eliminated within half the smallest beam reading the machine may be considered practically correct. Again, with regard to what extent it is desirable to carry the accuracy and sensitiveness of a testing machine, it will be generally conceded that engineers rarely care for anything in full-sized pieces beyond the hundredths place of figures. There are few lathes in the country that may be relied upon to turn a test piece perfectly round. There are fewer men who, with a tool capable of such extreme accuracy, have the skill of manipulation sufficient to produce a perfectly round piece, and there are still fewer gauges whose delicacy and accuracy are sufficient to measure a test piece of an inch or more in diameter to an error less than a thousandth of a square inch. Now, if it is impracticable to measure the area of the test piece less

than one thousandth of a square inch, which in iron corresponds to a variation in the testing machine of 50 lbs., and in steel to a variation of 80 or 90 lbs., and if the testing machine reads to $\frac{1}{8}$ or $\frac{1}{10}$ of the possible error of measurement in the test piece, is it not more desirable to direct endeavors to a more accurate gauging, rather than to a refinement of the weighing capacity and sensitiveness of the testing machine? Of course, in making experiments on turned or machined test pieces, accuracy of measurement and of weighing are both desirable, but the knowledge to be derived from such test pieces is simply the knowledge of the character of the material of which the piece consists. While the quality of the materials is a very important item, the consideration in the design of a structure the actual strength of the various members employed is, to the practical engineer and architect, of far greater importance. To cut a piece out of the center of an I-beam and to break it in a testing machine may give the investigator

a knowledge of the material of which a beam is composed, but when it is wished to know what load may be safely put on that beam when placed on the floor of a building, it is necessary to know the actual strength of the beam as a whole, and not the theoretical quantity obtained by calculation from a test piece, broken under circumstances entirely different from those which occur in actual use of the beam. Consequently the information desired at the present day is of the actual strength of members employed in construction, just as they are used, rather than that of carefully prepared test pieces which are broken under especial circumstances.

The difficulty of measuring a test piece increases about as the square of its size. If the piece be carefully machined, the errors of measurement may be estimated to be from $\frac{1}{1000}$ to $\frac{5}{1000}$ of a sq. in. per inch of area, while if bars direct from the mill are to be experimented on, the errors induced by variations in rolling, by flaws, seams and inequalities, by oxida-

tion and scale on the piece, may arise to an extent so large, that in I-bars of from 4 to 8 square inches in area there may be an error of $\frac{5}{100}$ or $\frac{8}{100}$ of a square inch. Thus, a possible error in the measurement of the test piece corresponding to from 2,500 to 4,000 lbs. may be introduced; consequently, if the testing machine is reliable to 25, 50, or even 100 lbs., and the error in the measurement of the test piece may amount to 10 or 20 times that quantity, the refinement of the testing machines seems to be hardly so much desired as refinement of measuring facilities.

One of the largest items of expense in making tests has been the necessity of carefully preparing each test piece to adapt it to the jaws of the testing machine. In many machines it has been necessary to select a piece considerably larger than was desired, and turn or plane it in the center so as to secure it to the testing machine. In fact, some specimens not long ago tested on one of the Rodman machines in Wash-

ington, the author was informed that some small test pieces of steel about 2 in. long and half an inch in diameter cost $10 each, simply to prepare them to be placed in the testing machine. This large item of expense has a very depressing effect upon the tendency to make experiments on the strength of material. The machine now under consideration has been specially planned to take in sections of any shape whatsoever in original size, so that those desiring to make experiments on real shapes, such as I-beams, channels, stars, and even railway rails, can simply cut a piece off the bar in question, send it to the testing machine, have it broken without the necessity of any machine work.

The spherical sockets previously alluded to for suspending the gripping wedges have four sides. These sides are inclined to the axis of the machine at an angle of about 12 degrees—two of them being curved and two of them being straight. By means of a series of wedges having curves and straight backs,

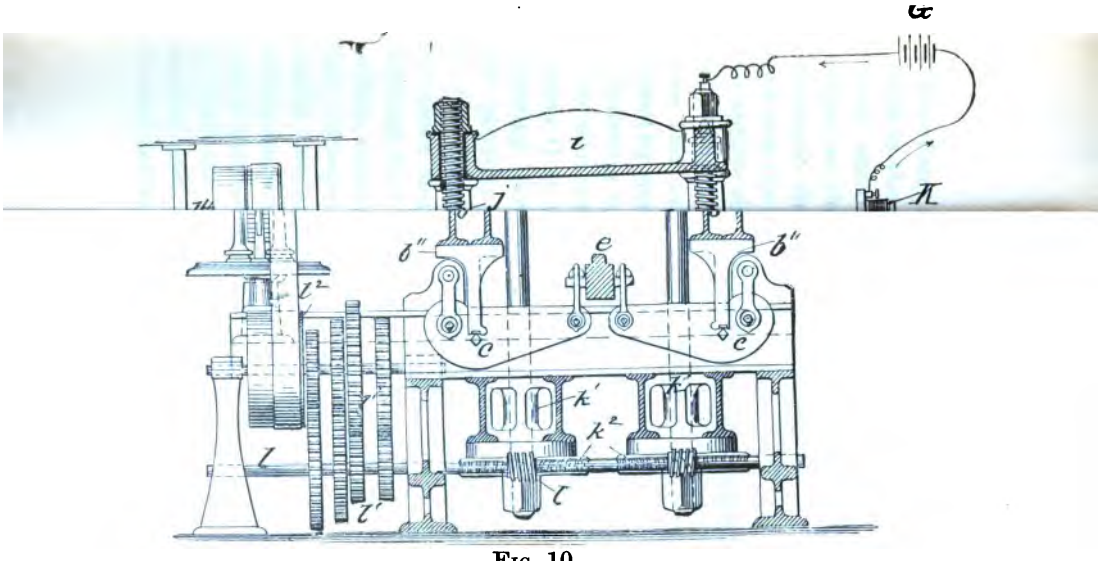


FIG. 10.

pieces of any section whatsoever may be placed in the testing machine and completely surrounded by the gripping wedges, so that the stress of the testing machine is firmly and equitably distributed over the entire test piece. Of course this applies simply to tests made in tension, while it will be perceived that transverse and other tests may be accomplished by similar contrivances.

Referring to Fig. 10 (the cross-section of the machine), it will be seen that the battery G is attached to the top of the adjusting screws HH. These screws are carefully insulated from the rest of the machine by standing on rubber bases and passing through rubber bushings held in the interior of the top casting, consequently these screws, with their corresponding cross-head, are electrically insulated from the rest of the testing machine, and being joined to one pole of the battery, form the only means by which the current can flow into the machine itself. As soon as the test piece is connected with the top cross-head it be-

comes thereby connected with the battery. On the lower end of the specimen may be seen a small clamp carrying an electro-magnet. One end of the wire of this magnet is in connection with the specimen, while the other end of the wire is joined to a little binding screw on top of the magnet, to which the other pole of the battery is attached, so that the current actuating this magnet flows through the test piece under examination. A magnetic clutch M, for holding the driving belt on the tight pulley, is also included in this part of the battery circuit. As long as the specimen remains intact the current flowing from the battery, excites the two magnets and attracts their armatures. When the rupture of the test piece occurs, the current is at the same instant broken, the magnets are demagnetized, the magnetic clutch M is released, the belt slides, by means of a counterpoise weight, to the loose pulley, and the testing machine stops. On the top of the specimen nearest to the upper cross-head is attached a second

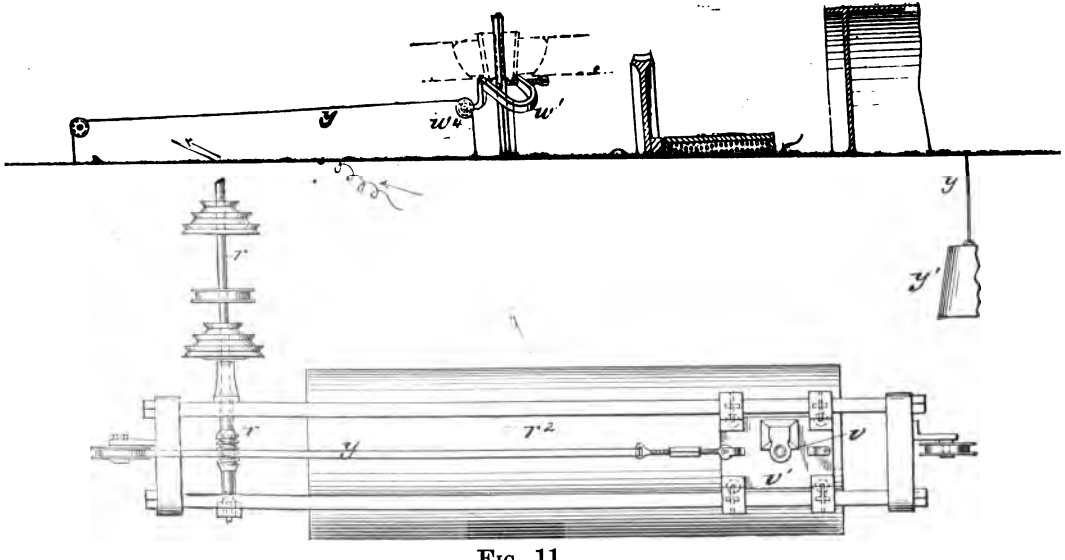


FIG. 11.

clamp, carrying a small sheave or pulley. Around this pulley, parallel to the specimen and attached to the armature of the lower clamp magnet, passes a flexible steel tape y. Referring to Fig. 11 an enlarged view of the specimen and clamp with its magnet may be seen. Here it will be noticed that the tape, after passing alongside the specimen, runs down to a pencil, or stylographic pen that is held in a carriage, placed over a metal cylinder carrying a sheet of cross-section paper. It is at once obvious that as fast as the specimen elongates under the action of the stress, the pencil is drawn along the cylinder parallel to its axis. This axis (the axis of x in analytical geometry) is assumed to be the axis of elongation. Inasmuch as the cross-section of the tape is very large in comparison with the friction of the pencil carriage and the supporting pulleys, the tape itself is subjected to comparatively little stress, and is always kept tight and in its place by means of the counterpoise weight y'; consequently,

every deformation of the specimen is accurately recorded on the cross-section paper by a corresponding motion to and fro of the pencil. In actual practice it may be said that the record of the cross-section paper corresponds within $\frac{1}{100}$ of an inch to the elongation measured on the specimen, and this for ordinary experimental work is sufficiently near. It will be noticed that the clamp is supplied with a spring and screw *w*. These screws are employed for securing the clamp to the specimen, and the spring serves to take any reduction of area caused by the drawing down on of the piece, and to constantly keep the clamp tightly secured in its place. Nearest to the magnet the side of the clamp is supplied with two edges, one rounded and one sharp. The sharp edge slightly indents itself into the specimen and secures the clamp rigidly into its place, while the round edge forms a zero mark from which the percentage of stretch may be readily calculated. The top clamp is made in a corresponding manner, and the sharp

Fig. 12.

edges are placed next to the jaws of the cross-heads. Consequently it is very rare that a specimen can break outside of these edges, and they then form data marks of reference, from which the deformation of the specimen may be calculated. The autographic record of the deformation of the specimen is by this means made plain. It now simply becomes necessary to record, at the same time the stress producing the deformation. Turning to Fig. 12 an enlarged view of the beam with the registering cylinder may be obtained. From this illustration it is perceived that the beam is composed of two parts, a top bar and a lower bar, each carrying its appropriate poise. The large poise is ten times as heavy as the small one, consequently the small one must move ten times as far as the large one to produce a corresponding effect on the scale. The entire travel of the small poise is equivalent to a weight of 10,000 in the testing machine, while the entire travel of the large one is equivalent to the entire capacity of 200,000 lbs.

On the end of the beam will be seen two mercury cups 16 and 17. The skeleton view of the beam with its apparatus shown in Fig. 13 may perhaps render this operation a little more obvious. From the lower cross-head of the testing machine, connected with the specimen, the electrical current flows into the butt of the beam. The two mercury cups at the end of the beam are so arranged that when the beam is in the center neither cup is included in the electrical circuit, which is consequently broken. If the force on the platform increases, the beam rises and the upper cup is brought into circuit and the current flows. Should the weight in the testing machine decrease, the beam falls into the lower cup, and the electric circuit is also completed by the drop of the beam. The lower poise is connected by means of the steel take with a little countershaft *r*. This countershaft is joined by an open and closed belt to two magnetic clutches t^4 and t^5. These clutches are placed upon the shaft that is driven by the clockwork

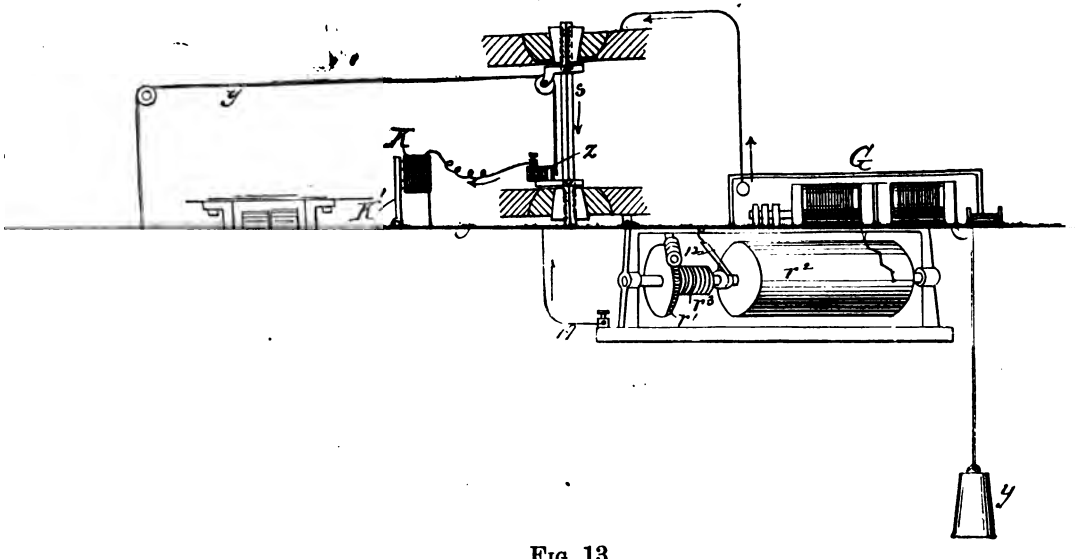


FIG. 13.

t. When the beam rises, the magnetic clutch t^4 is excited by the completion of the circuit through the mercury cup 16. As a consequence the small poise is immediately drawn out along the beam, tending to rebalance it. Should the motion of the poise equal the weight on the platform, the beam then sinks to the center, the circuit is broken, and the poise stands still. If the force on the platform decreases, the beam drops into the lower cup, the magnetic clutch t^5 is excited, the cross belt p^3 begins to move, and the poise is moved backwards on the beam, tending again to rebalance it. Returning to Fig. 12 a switch will be seen at 21, so placed that when the small poise reaches the maximum extent of its travel it strikes against this switch and automatically closes the electrical circuit through the magnet o^3. The effect of this circuit is to excite the magnet, release the large poise g^4, and cause it to move out $\frac{1}{10}$ of the travel on the top beam, which is exactly equivalent to the total travel of the small poise on

the lower beam. Instantaneously with the motion of the large poise the beam, superweighted, drops, closing the circuit in the lower cup and returns the small poise to the butt of the beam. It is plain that the rise and fall of the beam absolutely controls the motion of the poises, as the beam forms an automatic shunt for so circulating the electric current as to cause the poises to move to and fro. This motion of the beam is entirely dependent on the pressure exerted on the platform, so that a piece being placed in the testing machine the weighing may be done by the machine automatically in a way far more sensitive and accurate than is possible to accomplish by any hand labor however skilled.

In order to accomplish the registration of the motion of the poises which is all that is necessary to record the stress on the specimen, the cylinder previously mentioned is magnetically connected with the shaft *r*, so that as fast as the poises travel out, a worm-gear connected with the magnet on the cylinder causes the

cylinder to revolve circumferentially, thus making the axis of y the axis of stress. The motion of the pencil, as previously has been shown, records the deformation of the specimen, while the motion of the cylinder records the motion of the poises. By so proportioning the pitch of the worm-gear that an inch on the circumference of the cylinder corresponds to a definite number of pounds on the testing machine, it becomes an easy matter to read from the motion of the cylinder the amount of force which has been applied to the specimen, consequently the curvilinear line that is marked on the cross-section paper by the combined motion of the pencil under the influence of the tape and of the cylinder, gives a record whose abscissæ and ordinates are measures respectively of the stress to which the piece is subjected and the resulting strain. As soon as the piece breaks, the current which actuates both the motion of the testing machine, the motion of the tape and the motion of the cylinder is ruptured. The machine stops, the poises stand still and

the pencil comes to rest, leaving the record on the cross-section paper for any future inspection.

The preceding method of obtaining autographic diagrams possesses many advantages for adapting it to testing machines that are to be built especially compactly. There is another method of obtaining the same results, whereby the registering cylinder may be located at any distance from the the testing machine. in Figs. 14 and 15 are two photo-engravings from the beam and the registering cylinder employed in the "Department of Tests and Experiments." In Fig. 14 it will be seen that the beam consists of a single bar suspended on a stand at one end and enclosed in a guard at the other, while on this beam there rests a semicircular brass box forming the poise. Along the top of the beam, there is cut an exceedingly fine rack and the motion of the poise is obtained by a pinion placed inside of the box and gearing into this rack. At the end of the beam may be seen the mercury cups alluded to in the

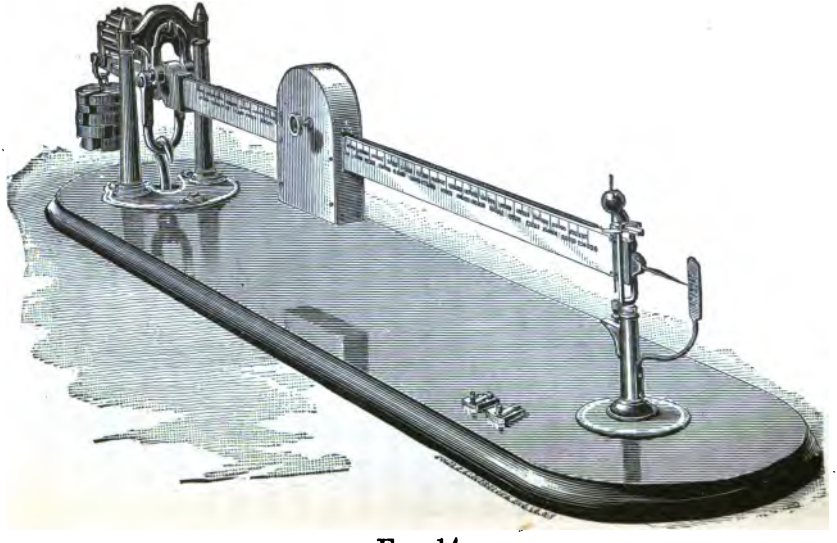


FIG. 14.

former method for making the electrical connection as the beam rises and falls. The operation of this piece of aparatus is substantially as follows: The clock-work motor for driving the poises to and fro on the beam, is connected with the mercury cup by means of some brass strips placed in the rear of the steel bar forming the beam. These strips are connected with two electro magnets on the inside of the poise, consequently when the beam either rises or falls, one or the other of the magnets is excited, the corresponding train of clock-work thrown into action and the poise gradually rolls to and fro until a balance is re-established. This part of the apparatus, that is the accomplishment of the motion of the poise to and fro on the beam, is exceedingly simple. The knotty part of the problem being to correlate the motion of the poise with the motion of the cylinder exactly so that in a given travel of the poise along the beam, the cylinder may move a corresponding quantity. Of course the ratio between the two movements is simply a

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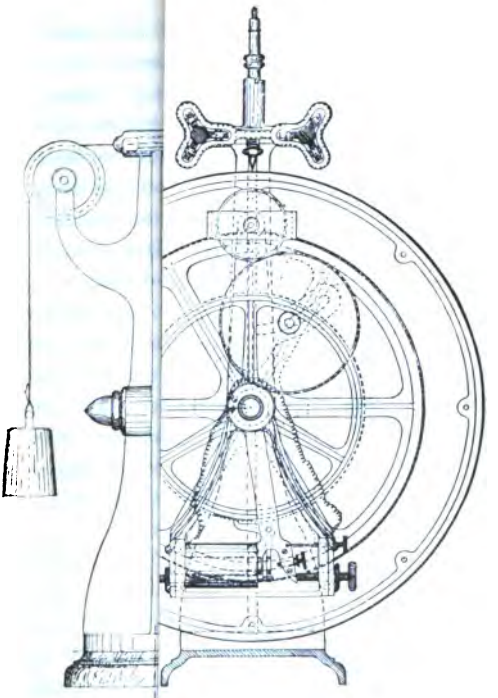
matter of proportioning so as to accommodate the ordinary cross-section sheet to the circumference of the cylinder, but an exact and constant ratio were very important. To solve this problem was to accomplish the solution of one similar to the autographic telegraph or electric clock and similar pieces of mechanism, but with some peculiar features arising only in this special instance. To go a little more into detail of the poise, there are enclosed in a brass box two large wheels about 8 in. in diameter. The wheel placed nearest the front of the poise is graduated with a series of numbers, corresponding to similar weights in the testing machine. The pinion carrying the poise along the beam is an inch in circumference, and consequently a single revolution of the pinion carries the poise one inch along the top of the beam. The dial wheel is secured directly to the pinion shaft so that there can be no backlash between the two, and being 8 in. in diameter one revolution of the pinion causes the dial wheel to travel 25 in. in circum-

ference. In the testing machine in question, a motion of an inch along the beam corresponds to a weight of 4,000 lbs. in the machine; and the dial wheel being graduated into 400 parts, each graduation corresponds to a weight of 10 lbs. in the machine. The other wheel is constructed in precisely the same manner as the dial wheel, excepting that in the place of the graduated marks there are little strips of india rubber so that the wheel presents a series of teeth, alternately made of india rubber and of brass. On the circumference of this wheel, there presses a brass commutator strip so arranged as to include the cylinder in its electrical circuit. When the poises commence to move along the beam, the teeth, alternately of metal and rubber, move under the commutator strip and with every passage of a brass tooth under the strip, an impulse of electric force is transmitted into the cylinder. In Fig. 16 a detailed view may be seen taken from the working drawing of the cylinder. Inside of the cylinder are two toothed wheels, which are mounted on a central

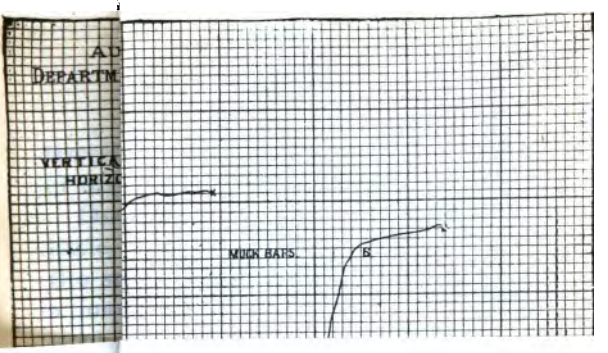


shaft and are capable of being ratcheted round by means of the little lever arm and pawl, operated by a magnet placed directly under each of the wheels. One of these wheels is intended to drive the cylinder in one direction, and the other in a contrary one. One electro-magnet is connected with a mercury cup on the bottom of the beam and the other with a mercury cup on the top. Consequently, when the beam makes connection with either cup and the beam commences to move, the corresponding electro-magnet in the cylinder is excited, the armature is attracted and commences to ratchet the cylinder wheel around. By means of a series of gears placed at the extreme right-hand of the cylinder, the drum is moved one way or the other in such a proportion that the motion of the poise may be accurately correlated with the motion of the cylinder. If the gears in the cylinder are accurately cut and properly proportioned, and if the armature of each magnet makes one stroke for every tooth on the poise wheel, the cylinder will

be moved to an amount that is exactly commensurate with the poise itself. At first it may perhaps seem that so accurate an arrangement would be almost impossible to construct, yet the same obstacle is presented in all machines of precision, but nobody objects to an engineer's transit or to astronomical telescope in consequence of difficulties in construction.

In machines already built it has been found perfectly possible to so correlate the motion of the poise with the motion of the cylinder that in the entire travel of each one, there should be a discrepancy between the two of less than 1-100 of an inch.

If the strip of cross-section paper on the cylinder be 40 in. long giving a stress of 4,000 lbs. to the linear inch, 1-100 of an inch corresponds to 40 lbs. This is about as fine a reading as can practically be made on cross-section paper, and as it is 4 times as large as the smallest reading of the poise it is obvious that this error of 1-100 of an inch on the entire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travel of the cylinder is too small to be of any practical value.

Over this cylinder is a track carrying a little carriage and pencil connected with the specimen by means of a steel tape, in a manner similar to that previously described. The cylinder and the poise are only connected, in a manner similar to the connection existing between two telegraph stations, consequently, if desired, the cylinder may be placed in one locality and the testing machine in another, so that it is perfectly possible for the cylinder to be entirely exterior to the control of the operator manipulating the testing machine.

Fig. 17 gives a photo-engraving taken from a sheet of cross-section paper bearing a half dozen of the curves autographically drawn by the testing machine. In this illustration the cross-section paper has been ruled in feet and decimals of a foot, and each of the specimens were one foot between the stretch clamps; consequently the percentage of stretch of the specimen may be at once read from the cross-sec-

tion paper. The lower half of the sheet contains three steel curves which, it will be readily seen, bear to each other a strong family resemblance. The curve commences with a straight line slightly inclined to the axis of stress at a constant tangent of one whose equation may be described as $y=ax$. When the elastic limit is reached a sudden point of inflection occurs, the tangent swinging around and becoming nearly or quite parallel to the axis of strain. Very soon, however, a second point of inflection makes its appearance, and the tangent nearly returns to its former inclination and the curve takes on a general parabolic form. These steel curves as well as the curve given by the specimen of Ulster iron may be taken as typical forms of curves to be obtained from a material which is nearly or quite homogeneous. The lines are quite true and regular, and the curve manifests little indications of non-uniformity in the material. As soon as the maximum stress in the specimen is reached, the material begins to reduce more rapidly at some

point of its length than the testing machine can keep pace with. Consequently, the stress on the specimen decreases gradually, while at the same time the strain rapidly increases. As a consequence of this, a third point of inflection occurs, the tangent inclining toward the axis of strain, and changing from a positive to a negative value. This proceeds until the specimen is ruptured and the apparatus comes to a stand still.

The other three curves given here were made by a piece of boiler plate and two specimens of muck-bar. These are exceedingly good illustrations of the value of the autographic method. It is well known that both boiler plate and muck-bar are decidely non-homogeneous, and as a result here the curves are exceedingly irregular, especially after passing the elastic limit. While a general resemblance may be traced to the preceding ones, they are full of points of inflection, and would seem to indicate that the material, being made up of fibres which were alternately elastic and brittle, was rupt-

ured by the continuing action of the stress in the testing machine, breaking one fibre after another, in very much the same way that a rope or cable is parted. To give a general record of a test it is believed that the autographic method is without parallel. As here described, however, it is not sufficiently accurate for careful investigation, into the limit and the modulus of elasticity. For instance, it is impossible to read on the cross-section paper nearer than about 100th of an inch, and any arrangement to magnify the stretch up to the elastic limit would so increase the elongation after passing that point, as to extend the curve beyond the capacity of the cross-section paper that is of an ordinary sheet. The autographic diagram will give the elastic limit within 1000 lbs. per square inch of cross-section and the modulus of elasticity within 100,000 lbs. Yet for many purposes it is desired to obtain a more accurate approximation to these quantities, and in Fig. 18 may be seen an illustration of a piece of apparatus devised by Col.

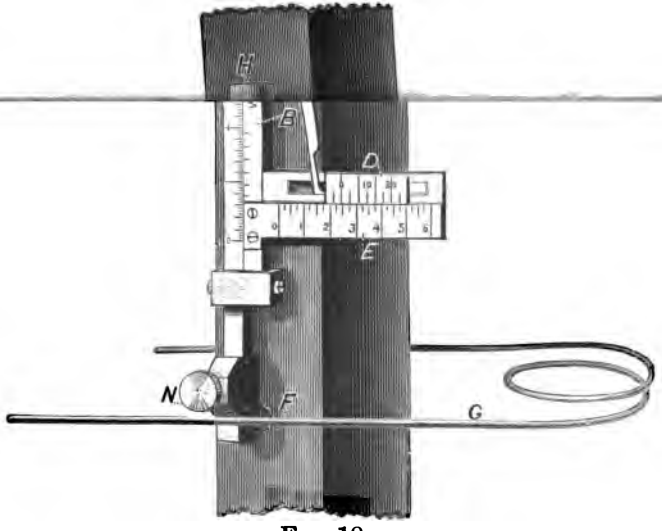


FIG. 18.

William H. Paine, of the East River Bridge, and used by him there in the investigations of the steel to be used in the trusses. It will be seen that the apparatus consists of two steel bars A and B, so arranged as to slide parallel to each other. At the ends each bar is supplied with a knife edge, F held in the sliding piece of brass M, which may be adjusted at the end of the bar. By means of these knife edges the whole apparatus may be clamped to the specimen by the use of the springs G. On the bar A, a small steel projection O, bears against one of the knife edges of the multiplying lever E, and the other end of this lever comes in contact with a supplementary vernier and scale D, E. Now as the piece under examination elongates, the bars move by each other, the multiplying lever C turns on its fulcrum, pushing the vernier D outwards along its scale. Thus it is obvious that the whole apparatus after being placed on the specimen works entirely without any intervention from the operator.

In the case of micrometer screws it be-

comes a pretty difficult matter for the same person to make readings twice alike, on account of the varying coefficient of friction and of the varying personal equation. And again the operation of making a reading with micrometer screws is exceedingly slow, and should, as in the hydraulic machines, the pressure have any tendency to relax, it is almost impossible to obtain a correct reading, whereas in the gauge in question the reading may be made as fast as the eye can gauge the coincidence between the vernier and the scale. In fact, in making many thousands of tests in the East River Bridge, at the Cambria Iron Works, the author used this instrument, and employing one man to place weights upon the beam of the testing machine, was accustomed to sit where he could see the vernier of the stretch gauge, and the moment that the beam raised to catch the reading on the scale, so that the entire operation of making a test on a bar one foot long, and an inch square, included the taking of some 20 to 30 read-

ings, did not occupy a time of more than 8 to 10 minutes, which is a speed never to be obtained by any arrangement of micrometer screws. By means of the extension piece and clamp L and M, the sliding bars of this apparatus may be extended to any entire length, and by this means it becomes an exceedingly valuable instrument in the investigations of stress which occur in structures already existing, such as bridges, roofs and the like. As a case in point may be mentioned an examination made by the author at the opening of the new cantilever bridge at Niagara. Two gauges were employed at the test of the cantilever bridge, vernier *a* being screwed to a tie-bar of the truss extending over one panel, and vernier *b* attached to the bar extending over two panels from the anchorage end of the cantilever on the American side. Vernier *a* extended over a distance of 4.75 feet, and vernier *b* over a distance of 5 feet of the bars. Readings taken at the various points at which the loading trains came to a stand, and gave the extensions

produced by a quiescent load, during the movement of the trains, the verniers fluttered a little, showing even at slight speed that there is a sensible effect from the shock, and as a loaded train moved off on the American side there was a negative reading of about $\frac{25}{100000}$ of a foot, showing a slight compression in the tie-bar. The following are the readings of the verniers reduced to a length of one foot of bar:

Train at Canadian abutment,

vernier a $\frac{10}{100000}$.
vernier b $\frac{12}{100000}$

Train at Canadian tower,

vernier a $\frac{74}{100000}$
vernier b $\frac{72}{100000}$

Train at Canadian end of center span,

vernier a $\frac{106}{100000}$
vernier b $\frac{132}{100000}$

Train at American abutment, giving the maximum stress in the rods under examination, . . vernier a $\frac{65}{100000}$
vernier b $\frac{212}{100000}$

Center span entirely loaded,

vernier a $\frac{106}{100000}$
vernier b $\frac{102}{100000}$

Bridge unloaded, verniers returned to zero. Assuming the modulus of elasticity on the eye-bars at 32,000,000 lbs., the following stresses per square inch are obtained from the preceding measurements:

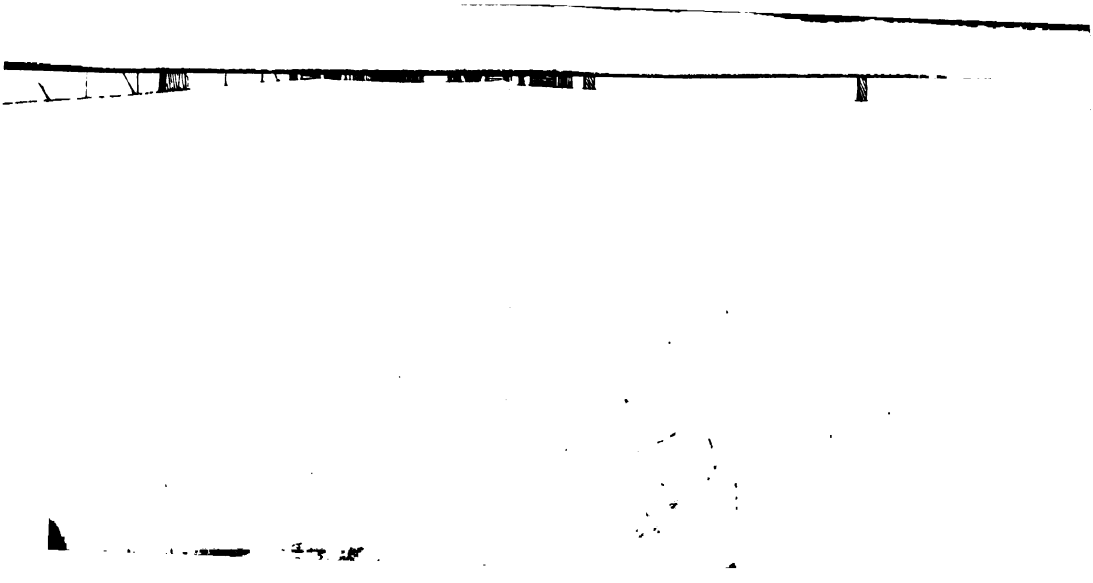
Bar extending from two panels, 6780 pounds per square inch.

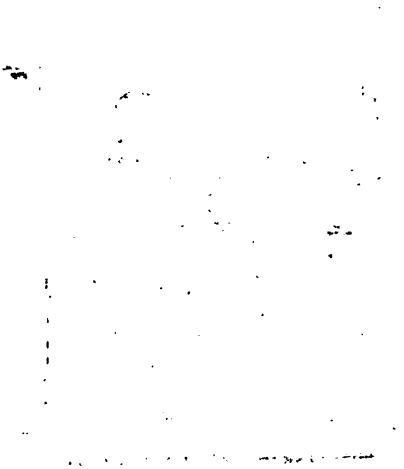
Bar extending from one panel, 5280 pounds per square inch.

Thus far vertical testing machines have occupied our attention. With the exception of the Emery testing machine, there are few machines of this class whose points of excellence demand attention.

During the construction of the St. Louis bridge. Capt. Eads built a couple of large horizontal machines, having a capacity of 500,000 lbs. While these machines, however, were superior to anything of the kind at that time, they were not sufficiently accurate to give results which were received with great confidence. They simply consisted of a long heavy framework, carrying a cross head

at the one end, with a hydraulic jack, and a pressure gauge attached for straining the specimen.. Consequently the only method of estimating the amount of stress applied was by calculating the pressure per square inch on the ram. As was conclusively shown in experiments with the Watertown machine, the coefficients of friction in the jack are constantly varying, sometimes introducing errors as high as 40 per cent. of the actual stress. Several long horizontal testing machines have been built by the Riehle Bros. for the purpose of making tests of chains, &c. These, however, were of small capacity, rarely rising over two or three hundred thousand pounds. One of the oldest horizontal machines of large capacity is that used in the Washington Navy Yard for investigations on chain cables, and with which all of the preliminary work of the U. S. Board to test iron and steel was made. This machine consists of along horizontal framework of masonry, carrying a hydraulic jack on one end with a scale at the other composed of two





levers. On the extremity of the second lever there hangs a large platform upon which a series of weights may be piled as fast as the stress upon the specimen increases, due to the action of the hydraulic jack. Of course this machine is laborious and cumbersome to manipulate, on account of the large number of heavy weights that have to be actually lifted and piled on the platform of the scale.

In Fig. 19 may be seen an illustration of a large horizontal machine which has just been constructed by Messrs. Fairbanks & Co. for the Edgemoor Iron Co. This machine consists of a long horizontal framework of wrought iron channels, upon which travels a hydraulic jack, carrying a three-piston pump, and driven by a belt supported on two idlers at the end of the frame. To accommodate the different lengths of specimens the jack can be run to and fro along the frame at pleasure, and be secured by means of 4 heavy steel pins which pass directly through each of the four columns composing the frame, between the parts of

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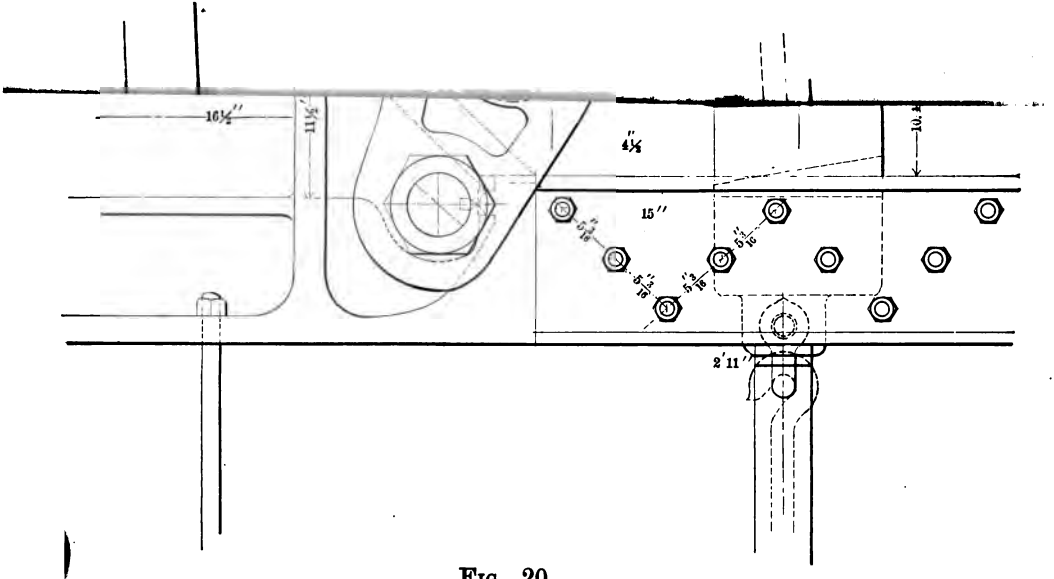

FIG. 20.

principal feature of this machine, which is different from those heretofore described, is the ease and facility with which it may be changed from tension to compression and conversely. Inasmuch as the jack is the double-acting one, all that is necessary in the straining mechanism is to alter the position of the valves at either end, so as to change the direction of the fluid in the pumps. The jack being secured to the frame by means of pins passing directly through the columns no change at all is necessary in this part of the apparatus, and the only remaining detail is to arrange the scale system so as to weigh, equally, stresses in tension or compression.

In Fig. 20 may be seen an enlarged detail of the main levers, with the device whereby this change is readily accomplished. Here it is seen that these levers are furnished with 5 pivots, the lower one bearing against a projecting toe on the main casting. The center has two edges instead of one and is surrounded by the casting forming the cross-head. The

next one bears against a projection issuing from the front of the main casting, while the two on the top of the lever have seats in the link for conveying the stress to the knee levers. Suppose, for example, a piece in tension: as soon as the jack commences operation, the tendency is to pull the lever towards the jack, the lower pivot catches against the toe of the main casting, and the linear motion is now converted into a rotary one around this pivot as a center, and the stress of the jack is conveyed to the knee lever by means of the link joining the two. Suppose the tension piece to be removed and the compression test substituted therefor, the tendency then upon the operation of the jack is to push the main lever away from it, and towards the large casting, $\frac{1}{8}$ of an inch play being allowed between the vertical lines of the pivots; the lower edge moves away from the toe of the casting, and the third edge strikes against its projecting seat. The result, as in the previous case, is to change the motion of the lever into a ro-

tary one around its pivot edge, and the stress produced on the jack is again converted into tension on the link connecting the top of the main lever with the knee lever; or, in other words, when the machine is acting in tension, the main levers are levers of the second class, and when it is acting in compression they are levers of the first class. By proportioning the pivot distances so that the multiplication is in both cases the same, a single set of levers answers both for tension and compression by simply turning down the little eccentric handle shown at the top, and throwing either one or the other of the link pivots into play. This machine in question has a capacity of 600,000 lbs. in either direction, and is capable of testing specimens between the cross-heads up to 12 feet in length. A peculiar feature, however, is that the scale cross-head has an extremely large opening, and the framework is entirely open directly behind it, so that eye-bars or tension pieces of any length may be easily tested. If, for example, it is

wished to test an eye-bar 40 feet long, the bar is introduced through the opening in the scale cross-head and the eye screwed to the cross-head of the jack, while the metal of the bar is gripped by means of wedges placed in the scale cross-head. That this is a fair test and gives all the information to be obtained from a testing machine of much longer dimensions will be readily seen from this fact: First, if the material of a bar is to be tested it can be done equally as well in a length of ten ft. as in a length of 40 ft., and if the construction, method of formation, or proportion of the eye is to be tested in relation to the bar, this is secured by the presence of one eye attached to the cross-head of the jack. Should it be desirable to test both eyes of the bar, this can readily be done by first breaking one and then turn the bar end for end and breaking the other one. Of course, this double test of a single bar requires a little more time, but to compensate for this the space occupied by the machine, the expense of construction, and the labor of

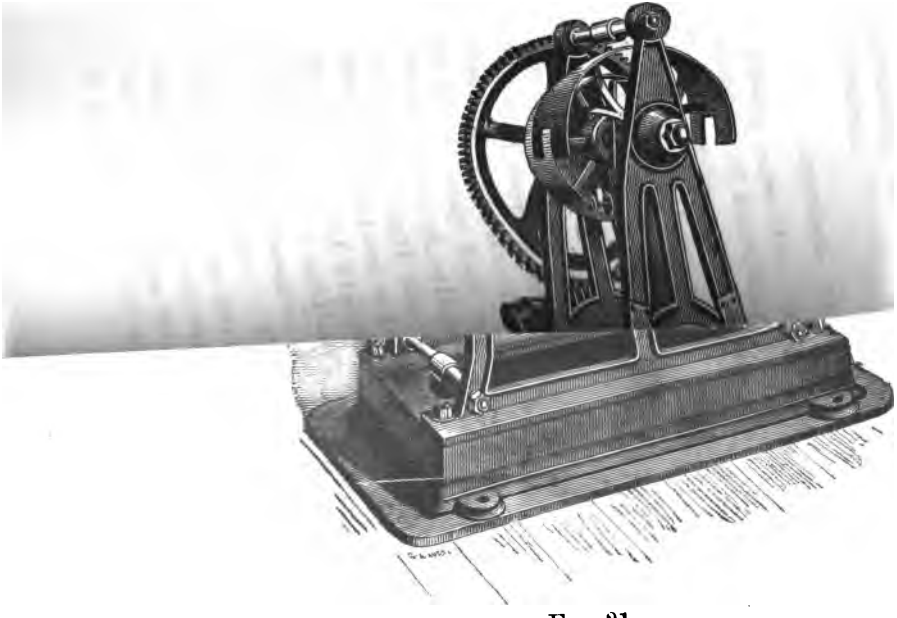

FIG. 21.

manipulation, are reduced to an enormous extent.

SPECIAL MACHINES.

Passing now to our second general subdivision of testing machines, we come to the consideration of those which have been designed for special purposes, and perhaps the first and most notable among these is the autographic torsion machine of Prof. Thurston. Fig. 21 is a perspective view of this machine, and in Fig. 22 a front elevation, a longitudinal section on line *aa*, and a transverse section on line *aa'* may be seen. The machine consists of two A-shaped frames AA, A'A', and shown in all the figures. These are firmly mounted on a heavy bed-plate. Near the top of each of these frames are spindles C and D, each of which has a rod E and H, with a jaw to receive and hold the heads of the specimens. The two spindles are not connected in any way to each other, except by the specimen itself when placed and adjusted to be tested. To one spindle a long arm HB is attached. It carries a

heavy weight B attached to its outward end. This spindle has a worm wheel driven by a worm J on the shaft LL′, which is turned by a hand-crank K. When the specimen is placed in the two jaws, and the spindle is turned by the worm gear, the effect is to twist the specimen. The position of the arm and the weight will at all times be a measure of the torsional stress which is exerted on the specimen; but as this torsional stress is increased the specimen commences to give way or be twisted by the stress, according to the quality of the material. In making such torsional tests it is essential that the amount of twist should be known. If a record of this could be procured, it would be an indication of the capacity of the material to resist such stresses, or, in other words, of its quality. This testing machine was designed for this purpose. The record is made in the following way: To the spindle C a cylindrical drum is attached, which is covered with a sheet of cross-section paper. To the arm N a pencil holder is attached at *f*, and carries

a pencil *d*, the point of which bears upon the paper of the drum. Supposing that the specimen in the machine should offer no resistance, and should merely twist, the pencil would then remain stationary, and as the drum is revolved the pencil would trace a straight line on the paper, the length of which would measure the amount which the specimen was twisted. If, on the other hand, the specimen be supposed to resist and to twist simultaneously, as is always the case, it will be seen that the spindle D would be turned, and the arm N would be moved from a vertical position to a distance proportionate to the stress resisted by the specimen. The pencil holder attached to the arm would move with it. To make a record of this distance a guide curve FF′ is attached to the frame of the machine, so that when the arm N and the pencil holder are moved out of their vertical position the pencil is moved towards the left by the guide curve, which is of such a form that the lateral movement which it gives to the pencil is proportional to

the moment of the weight on the end of the arm. In this machine each inch of ordinate denotes 100 foot-pounds of moment transmitted through the test piece, and each inch of abscissa ten degrees of torsion. By use of this machine the metal tested is compelled to tell its own story, and to give a permanent record of its strength, elasticity, and every other quality which is brought into play during the test.

The transverse testing machine of the Stevens Institute, Fig. 23, built by Messrs. Fairbanks & Co., consists of a heavy platform scale, on the platform of which stands a cast-iron frame, to which are fastened the supports DD at the required distance apart. The pressure on the specimen is applied by means of a hand wheel on the upper end of the screw K, which screw passes from the nut E, and terminates in the sliding cross-head I. This cross-head serves both as a guide and as a pressure block. The test piece L, rests upon mandrils mounted upon the supports DD, at the required distance

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apart. All the loads are weighed in the usual manner at M.

A second example of transverse testing machine given in the illustration Fig. 24, is one which is especially designed to meet the requirements of makers and users of cast iron. The construction of the machine is exceedingly simple, and may be almost seen at a glance. A wooden framework supports a hand-wheel for applying the stress to the specimen, which is hung from the end of a lever supported close to the wheel. The end of this lever carries the stress to the weighing beam, where it may be estimated by sliding the poise to and fro, and adding the weights to the weight counterpoise.

Perhaps next to iron and steel the material most frequently tested is cement, and in the illustration, Fig. 25, may be seen an automatic cement-testing machine. On the pedestal of the machine there stands a column A, supporting on the top a receiver B, to which is attached the scale work of the machine. Perhaps

its operation may be clearly understood by describing the method of making the experiment. The cement being mixed with the necessary quantity of water, is pressed into the moulds M, and having stood a sufficient time to set, the mould is removed by opening the clamps and sliding the two side pieces away. After the briquette has attained the requisite age it is placed in the clamps NN, the hand wheel P is turned, drawing down the lower clamp and taking up the slack so as to raise the scale beam nearly or quite to the top of the guard K. The reservoir B has previously been filled with shot, and by opening the valve J this shot is allowed to run from the tube I into the pail F. The weight of the shot flowing into the pail constantly increases the stress on the briquette between the clamps NN. As soon as this stress reaches the tenacity of the specimen in question, the briquette breaks, the beam D drops, and striking the valve J, shuts it up, cutting off the supply of shot. The pail with its shot is now detached

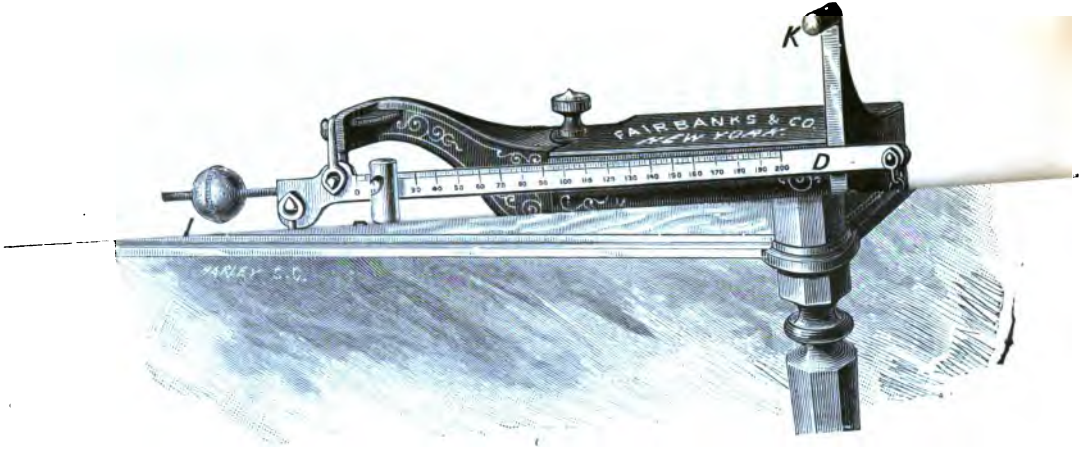
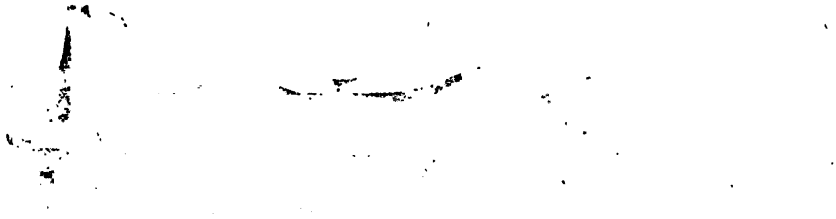


FIG. 25.



from the end of the beam, and hung on the hook on the under side of the balance ball E. In the place of the pail is hung the counterpoise G, which exactly balances the weight of the pail, thus leaving only the amount of the shot contained therein to affect the scale. By sliding the poise R to and fro on the beam, or by adding on the counterpoise the weights H, the amount of the shot required to break the cement may be readily and directly read from the beam The beam is graduated to 200 lbs., and with the addition of four small weights a capacity of 1,000 lbs. is obtained.

The elasticity of car springs, and the amount which they will deflect under a given load has lately become a matter of much investigation, for the railway companies constantly increasing the loads in their cars and running at higher speeds, require springs which shall be correspondingly safer and more durable to support the heavy use to which they are subjected. Fig. 26 is an illustration of a machine designed to meet the wants of car spring

manufacturers, so that every spring that is made may be, as fast as it is completed, tested, to ascertain whether or not it fulfills the specifications that it is intended to meet. A heavy cast iron framework supports a cross-head carrying an adjustable plunger. This plunger may be raised or lowered by means of a screw thread cut on it, so as to accommodate any length of spring from two inches to three feet. Directly beneath this plunger there is a bed plate for supporting the spring, which forms a platform of scale. The other end of this lever stands on a lever directly inside of the casting that conveys the stress received by the spring to the scale beam, where, by means of a sliding poise and the large weights, its quantity may be correctly estimated. The gearing and the belt at the back of the machine form a means by which the plunger may be moved up and down. For example, supposing a railway company has issued specifications for 10,000 springs 6 in. in height, which shall carry 10,000 lbs. and deflect 7-8 of an inch under a load. The

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spring maker coils a spring which he supposes will answer the requirements, and placing it in a testing machine, so adjusts the cross-head that it shall depress the spring 7-8 of an inch. The machine is then started and the weights added to the scale beam until a balance is obtained at the given deflection of the specification. If the weight thus indicated corresponds with that of the specifications, the spring maker knows that the spring in question will answer the requirements, and he goes on to fill his contract. If, however, the spring be either too stiff or too weak, a corresponding change must be made in the article. Having completed the entire contract the machine is adjusted to give a deflection of 7-8 of an inch, and as fast as the springs are ready, each one is placed in the machine. A glance at the spring balance, attached at the underside of the weight counterpoise, will tell the exact number of pounds that the springs sustained with a deflection corresponding to that inserted in the specification. All the springs which fulfill the requisite of

weight may be confidently shipped by the manufacturer, while those that for any reason fail, may be returned to the factory. With a machine of this kind the manufacturer has a guarantee that all of the entire product must be accepted by the railway company as fulfilling their specification.

THE USE OF THE TESTING MACHINE.

The investigation of the physical properties of materials used in construction may be analytically divided into four parts:

1st. The investigation of the qualities of a special material. For example, the engineer may wish to ascertain the tensile strength, ductility, and resilience of a special steel.

2d. The manufacturer may wish to ascertain variation in quality produced by a change in the chemical composition of the metal forming his output. For instance, in the processes of the open hearth or the Bessemer converter, changes in the relative proportion of

carbon, manganese or phosphorus may produce the greatest changes in the physical properties of the steels produced.

3d. The manufacturer or the consumer may wish to ascertain the changes produced in material by means of the different mechanical processes to which it is subjected while being shaped into the proper forms required by different structures. A noteworthy example is the various methods by which eye-bar heads are formed.

4th. The actual strength, elasticity, or resistance of a member forming one of the parts of a bridge or other structure may be desired, either for information as to the best method of design, or from which the actual strength of the structure in question may be ascertained.

These various subdivisions will now be treated in their appropriate order.

CARE ON THE PART OF THE OPERATOR.

The manipulation of the testing ma-

chine in order to obtain therefrom the most accurate and reliable information, embracing all the facts and data to be obtained from an experiment, is an operation requiring on the part of the manipulator the greatest exercise of care and skill and watchfulness. In making experiments on ordinary test pieces of a few inches in length, the operator is constantly dealing with two sets of quantities: one the measurement of the size of the test piece, and the amount of deformation produced by the stress previous to the elastic limit—involves the use of the most minute quantities. An error in the measurement of the piece of a thousandth of an inch, a quantity far too small to be appreciated, except by the most delicate means of measurement, may induce errors in the result sufficiently large either to condemn an otherwise good material, or to accept one which is inferior. In the measurements of the deformation of the piece under the action of the stress, the quantities are still smaller, reaching to a ten thousandth, or

even to a millionth of an inch, so that it will be obvious that during this part of the operation the greatest care is necessary to observe most carefully and accurately all of the circumstances which take place. The measurement of the stresses exerted by the machine running to thousands or hundreds of thousands of pounds, requires an exercise of skill in quite a contrary direction. It is not only necessary to measure these stresses accurately, but at the same time the mind of the operator must have sufficient flexibility so as to turn rapidly and easily from the consideration of a very small quantity to one which is exceedingly large. The entire behavior of the piece under the operation of the stress is one which requires the minutest attention. The equal or the unequal yielding of one side or the other, the appearance of the piece as under the operation of the stress, the fibers are torn apart, the surface becoming blistered, seamy and uneven, appeal in the most eloquent manner to the eye of the skillful investigator. The

amount of deformation produced by the stress, and the way in which it takes place, whether the piece uniformly yields under its stress, or whether the yielding takes place at one particular point, may convey most important information as to the character, qualities and suitability of the material under investigation.

Placing the test piece in the testing machine is an operation requiring most careful attention. It is necessary that the piece should be so arranged that its axis may coincide with the axis of stress produced by the testing machine. Even in the machines so designed as to furnish automatic means of centering it is still necessary for the operator to exert the most unceasing vigilance to see that the piece is correctly surrounded by the jaws of the machine, to insure that these jaws exert an equal bearing all over the surface, that it is properly set in line, and that the entire adjustment with reference to the various parts of the machine is done in the most careful and accurate manner. This adjustment of the test

piece is especially essential in experiments upon metals which are crystalline, stiff, and unyielding, such as cast iron. Mr. Hodgenson states that the strength of a rectangular piece of cast iron so placed in the machine as to cause the stress to pass along the side of the piece is only one-third of the strength to resist a central stress. It is evident that this ratio would perhaps be given only by a few forms, subjected to tension in a peculiar manner, and that it probably would vary with every change in shape and position of the test piece. In machines not furnished with self-adjusting jaws the importance of this care in setting the test piece can hardly be too strongly insisted upon. It has frequently happened in the experience of the author that in making experiments upon plate iron the piece would be so placed in the testing machine as to be torn apart rather than fairly broken. In many experiments the bend of the test piece after rupture was markedly perceptible to the eye. The errors in such experiments

may rise as high as twenty or thirty per cent. of the actual strength of the piece in question.

THE APPEARANCE OF THE FRACTURE.

After the completion of an experiment a careful examination of the test piece should be made, and the character and appearance of the fracture should be carefully noted as an index of the quality of the material. Good wrought iron, when broken by tension, should present a fracture resembling a bundle of fibers, having a dark gray color. There should be little or no appearance of lamination due to the piling and the rolling of the bar, and no appearance of any bright or crystalline spots. The fracture should be irregular, inclining towards cup shape. The general appearance of the fracture of good wrought iron is indicated in Fig. 27. In the poorer qualities of wrought iron it is very customary to find the bar interspersed with a greater or less number of bright, shining crystalline spots, similar in appearance to

cast iron, excepting that the crystals have very much higher metallic luster. The

FIG. 27.

relative proportion that the crystalline spots bear to the whole area of the piece may be taken as a very fair index of the quality of the material. Fig. 28 gives a representation of the fracture of the medium quality of cast iron, showing about one-third of its area to be composed of these hard crystals. Such iron

may stand a very high tensile stress, but it will show very little ductility. This

FIG. 28.

crystalline structure of the bar may be due to one of two causes. Either the iron contains too large a proportion of phosphorus, and so is termed cold-short, being exceedingly brittle and unworkable when cold, or else during some processes of the manufacture the bar was overheated (burnt, as it is said in the black-

smith's shop) and allowed to cool with insufficient mechanical work. The cold-shortness attributable to too large a quantity of phosphorus is not indicated by any exterior appearance of the bar, whereas, if the iron has been burnt, the exterior is blistered and rough, showing to the practiced eye that there has been overheating, by which the more fusible parts of the bar were actually melted.

The length or size of the fibers in the fracture is an exceedingly good index of the value of the material. Fractures which occur with short and apparently brittle fiber, rather fine in texture, generally indicate an iron which will when cold possess considerable ductility, yet probably has such a proportion of sulphur as to make it red-short and exceedingly troublesome to manipulate under the hammer. The results of irons of this kind may be fairly good in the testing machine, yet as far as is possible they should be avoided in construction on account of the difficulty of obtaining good results from shop manipulation.

During an experiment on wrought iron, as soon as the elastic limit is passed the surface of the specimen, if it has previously been machined, gradually loses its bright metallic luster and becomes rough and mottled under the distorting effect of the stress. In the finer and most superior irons this mottling of the surface is exceedingly delicate. The fibers of the piece seem to be rumpled and distorted by the stress so that the whole of the surface is thrown into an innnumerable number of minute ridges. In the coarser and less valuable irons this mottling of the surface is comparatively heavy and uneven and the want of homogeneity in the structure of the metal is clearly indicated by the uneven appearance of the test piece.

The fractured surfaces of steel bars present a far greater variety than those of iron specimens, in fact there are at least a dozen or fifteen different appearances in steel indicating corresponding changes in the value of the metal. The appearance of the fracture of good con-

structural steel, having an elastic limit of from forty to fifty thousand pounds, and an ultimate of from seventy to eighty thousand is a light silky gray. One end of the test piece, broken by tension, being a slightly truncated cone that fits into a corresponding concavity in the other end. Steel fractures, excepting those of the poorer varieties, should rarely be termed fibers, for the texture of the metal is so exceedingly delicate as to be only comparable to the finest silk. Steels made by the Bessemer process generally present a fracture which is darker and a little more corky in appearance than those made by the crucible or the open hearth methods. As the amount of carbon increases, the tensile strength and the elastic limit are increased, and at the same time the silky and conical appearance of the fracture gradually decrease, until, when the tensile strength rises to a hundred thousand pounds per square inch, the silky appearance is almost entirely lost, the fracture becomes square, showing little reduction in the bar and presenting

a granular appearance made up of small brilliant crystals. The same appearance of the fracture may be produced by an excess of manganese. In such steels the tensile strength may not rise over sixty to eighty thousand pounds, yet the character of the fracture is by the presence of the manganese entirely changed from that of the fine delicate texture of the carbon steel to a coarse and granular appearance almost resembling that of cast iron.

The effects of phosphorus and sulphur are similar to those produced in iron. An excess of phosphorus renders the piece cold-short, reducing the amount of reduction and giving the fracture a more granular character.

The following classification of the characteristics of fractures is presented, hoping that it may in some measure aid towards uniformity in description.

STEEL FRACTURES.

First, square.—Those in which the plane of the fracture is nearly at right angles to the axis of the test piece.

SECOND, IRREGULAR.—Those in which the plane of the fracture is inclined more or less to the axis of the test piece and in which the fracture presents one or more jagged points.

THIRD, CONCOIDAL.—In which one end of the test piece presents a cone matching in a corresponding conical socket in the other half.

AS TO MOLECULAR STRUCTURE.

FIRST, FINE CRYSTALLINE.—Fractures such as are presented by the rupture of the best quality of tool steels, in which the bar seem to be made up of an infinite number of exceedingly fine and iridescent crystals.

SECOND, CRYSTALLINE.—Such fractures as are presented by the coarser qualities of tool steels, or by the higher grades of structural steel containing large amounts of carbon or phosphorus. Here the fracture is composed of larger crystals, losing to a great extent their iridescence and seeming to be grouped in radial lines around the center.

THIRD, SILKY.—Fractures which are manifested by the best varieties of structural steels in which the crystalline appearance is entirely lost, inasmuch as the crystals seem to be merged in long bundles of the finest and silkiest fibers.

FOURTH, GRANULAR.—Fractures of this kind are manifested by the inferior varieties of structural steels, and seem to consist of a large number of granular crystals of considerable size, grouped in radial lines around a central axis.

FIFTH, COARSE GRANULAR.—Fractures of this class are only manifested by the inferior qualities of structural steels and are generally indicative of too high a per centage of manganese. In such cases the crystals are large and coarse, presenting many glimmering facets and having almost the appearance of the poorer qualities of wrought iron.

WROUGHT IRON fractures may be classified into square and irregular, as follows :

Square fractures are presented only by the inferior crystalline varieties that break sharply and shortly with but little

or no reduction or elongation. As the quality of the iron becomes better, and the crystalline texture disappears, the fracture becomes more and more irregular, until, when a pure fibrous iron is attained, the fracture may occur at a plane inclined to the axis of the test piece at any angle, and presenting many jagged irregular points. The square fractures are always exceedingly crystalline, presenting a great number of large crystalline facets, having an exceedingly high metallic luster. The irregular fractures may be divided into long fibrous and short fibrous, depending simply upon the relative length of the fibrous structure.

Fractures of cast iron may be divided into, simply, fine crystalline and coarse crystalline, depending upon a relative size of the crystals. The coarser and less refined varieties of cast iron present, when broken, a fracture which is made up of a large number of dark grayish crystals, interspersed here and there with traces of graphite. Upon remelting and refining the texture of the fracture, by

each succeeding operation it becomes finer and finer, until, in the best refined iron, we have a fracture which is made up of exceedingly fine gray crystals, having but little metallic lustre and giving no evidence of graphite.

EFFECT OF THE SIZE OF THE SPECIMEN.

In making experiments upon the *qualities* of material the first point to be considered is the size and shape of the test piece and effect which this produces upon the results to be obtained from the testing machine. The variation of the form of the test piece considerably modifies the apparent tenacity of ductile material; consequently it is necessary to note the size and shape of the specimen to be tested, in order that the results obtained from the experiment may be correctly compared with those of previous or future results. When a piece of metal is subjected to tensile stress, and slowly drawn in two, it will yield at the weakest section first, and if that section is of considerably less area than the adjacent

parts, or if the metal is crystalline and unyielding, it will break sharply and without appreciable stretch, the fractured surface having a granular appearance.

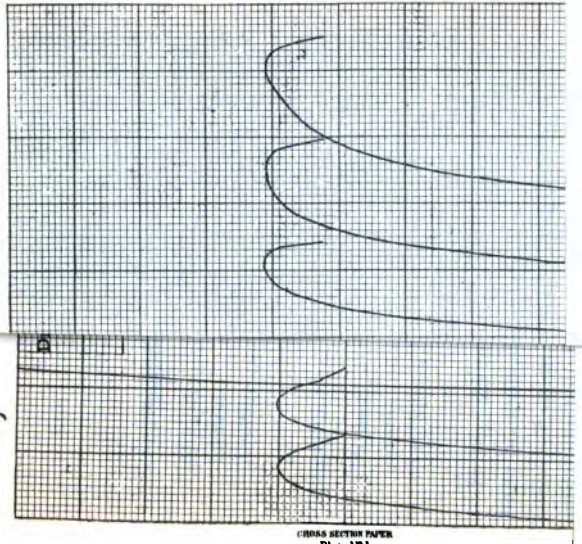
On the contrary, if the test piece has a uniform section of considerable extent, it will gradually stretch with a uniform reduction of section from end to end. Toward the ends where the piece is grasped by the machine this reduction of area is least perceptible. When the stress has obtained so great an intensity that the weakest section is strained beyond its elastic limit, the molecules of the metal commence to flow, and the piece gradually reduces in cross section, the particles immediately adjacent to the over-strained portion flowing towards the section of greatest stress. If, however, the shape of the specimen is so arranged as to prevent or to retard this flow of metallic molecules, the result is to largely increase the apparent tenacity of the material. This increase of tenacity due to the shape of the specimen has been suspected for many years past; but has only re-

ceived a complete demonstration within a comparatively short space of time. The United States Board for making tests of iron and steel, made a series of experiments to ascertain the relative value of specimens having long or short uniform sections. The results of these tests are presented in Table I.

TABLE No. 1.

Prog. No.	Specimen L″	E. Lim lbs. □″	Ult St. lbs. □″	Elong. %	Reduc. %
1	5 00	26795	51989	30.	49.3
2	3.938	28194	52389	32.	50.0
3	4.500	28062	52495	30.	46.3
4	3.500	27268	53052	31.6	48.0
5	3.000		52984	33.0	48.0
6	2.472		52852	32.1	45.6
7	1.989		53169	32.9	45.0
8	1 500		52666	35 0	45.2
9	1.000		53169	35.4	43.5
10	.500		57818	41.6	36.6

Some experiments have given the following results from Bessemer steel specimens:



CROSS SECTION PAPER
Plate No 1.

TABLE No. 2.

Grooved Specimen—

Highest	162974
Lowest	136490
Average	153677

Long Cylinder—

Highest	123166
Lowest	103255
Average	114460

In Fig. 29 may be seen the curves that have been obtained from a series of specimens of open hearth steel, made under the direction of the author in the following manner. From a bar of steel sixteen feet long there were cut twelve pieces. Each of these pieces was placed in a lathe, and one cut taken over it so as to render the piece perfectly straight and true. The series of steel pieces thus obtained, all cut from the same bar, were turned to lengths of uniform diameter, as seen in the column headed "Lengths" in the accompanying Table 3.

TABLE No. 3.

Dimensions of Test Piece.			Stress Tension in lbs. per Square Inch.				Elongation per cent.	Reduction per cent.
Length in inches.	Diameter in inches.	Area in square inches.	Elastic Limit.	Maximum.	Ultimate.	On reduced Area.	Ultimate.	
Groove	1.000	.785	Elastic limit taken by fall of beam. Not perceptible before this point.	79286	78930	99614	Infinite.	20.77
.25	"	"		71138	70070	88530	100.00	20.85
.500	"	"		66446	64306	84983	60.00	24.38
.75	"	"		63036	61224	87114	46 66	29.72
1.00	"	"		62637	59707	87771	40.00	31.97
2.00	"	"		61671	57398	89463	30.00	35.84
3.00	"	"		61161	56122	94017	29.30	40.31
4.00	"	"		39642	61253	56226	94602	27.50	40.54
5.00	"	"		39667	61125	56226	94421	25.00	40.41
6 00	"	"		39515	60778	56250	94839	23.66	40.69
8.00	"	"		39235	60778	56226	94218	22.50	40.43
10.00	"	"		39158	60735	56250	94839	22.00	40.69

From these experiments it will be seen that the uniform length of the piece under examination exercises an exceedingly important part in the results obtained from the experiment.

In explanation of the cause of the difference in the flow, and the increased tenacity of the grooved specimen over one having for considerable length a uniform section, let it be supposed that a single chain of molecules of a ductile metal be subjected to tensile test, and let the length of this chain be ten inches. Under tension, each molecule would become separated from its neighbor, as far as their cohesive attraction would allow, on releasing the stress the molecules would resume their original places, no permanent extension having taken place. The greatest distance which one molecule could be separated from its neighbor would be an infinitely small quantity, and the total of the numerous extensions would probably not exceed one or two hundredths of an inch in the length of a ten-inch chain. This separation would

represent the real limit of elasticity, which, if exceeded, would be followed by rupture. The stress causing this temporary extension would be the elastic limit, the tenacity and the tensile strength of the material. If the extension were carried beyond this, the chain of molecules would break, but each of the broken parts of the chain would show no indication of permanent set.

A test bar may be conceived to be made up of a number of these chains of molecules, each link having the peculiar property under high tension of leaving its own chain and taking up a position between the two nearest links of the next chain of molecules. These chains may thus become permanently elongated by the addition of new links, but they are at the same time reduced in number. The permanent elongation of the specimen is an indication that such a flow of molecules has occurred. The direction of this flow is from the exterior to the interior, as is proved by the reduction (always observed at the point of fracture)

in a ductile material. Each chain in the aggregate may be supposed to be capable of bearing the same stress as if tested alone, or as if it had not become elongated by the addition of the neighboring molecules; but as the chains are fewer in number, the total stress carried by the whole, prior to rupture, is less than if the flow of molecules could have been prevented. For example, it is obvious that one hundred feet of ordinary iron chain, having a strength of one hundred pounds, may be divided into ten equal lengths of ten feet each, which by their combined tension might be made to support a load of one thousand pounds; but if the chain be divided into five parts, each twenty feet long, the united strength would only be five hundred pounds. In the case of a test piece, each molecule is not only a link of the chain in longitudinal direction, but it may also be regarded as a constituent link in all directions. In an ordinary ten-inch cylindrical specimen the end links of the transverse train of molecules come to

the surface and are free. They therefore offer no resistance to flow in the transverse direction. In a grooved specimen the transverse molecular chains are not free, but are united to the ring of external metal. If this ring be of sufficient strength to resist the transverse stress, the reduction of the area of the piece would be almost, if not entirely, prevented, and consequently the tensile strength per square inch will approximate to the tenacity of this specimen—using the word tenacity to mean the strength calculated on the reduced section of the piece. Consequently, in a grooved specimen the additional strength thereby obtained may be regarded to be the sum of the tensile strength of the piece, plus the amount of force requisite to prevent the flow of metal and the ordinary reduction of area. In proof of this an examination of column of "tension per square inch of reduced area," in the above series of steel tests, will show that the ultimate tenacity of the piece obtained by calculating the ultimate breaking strength as the re-

duced area of the piece, is nearly a constant quantity. To measure accurately the exact size of a broken test piece is a matter of considerable difficulty, and the variations in the foregoing column may probably be regarded to be due more to the inaccuracies in the measurements of the reduced area rather than to deviations from the above expressed law. Experiments of various grades of iron and steel have certainly indicated the probability that each particular grade of metal has its own ultimate of tenacity, so that if the tenacity of the piece be calculated upon the reduced area after fracture, a constant quantity would be obtained for each of the different grades of metal for every different length of test piece.

The importance of specifying in contracts for iron work, the exact size and shape of the pieces to be tested, has thus been rendered very obvious.

It is to be regretted that the size of test pieces has not been even more rigorously proscribed, and it is now sug-

gested that engineers in framing iron and steel specifications, would do well to carefully indicate the exact size, shape and other circumstances governing the specimens to be tested.

THE EFFECT OF TIME OCCUPIED IN MAKING THE TEST.

It has previously been indicated that one of the first effects of stress on a ductile material is to cause the molecules to flow from the exterior towards the center. The question of the time occupied in making an experiment would seem to be an important one, and doubtless if the rapidity of the test is so great as to cause the stress to approximate towards a blow or a shock, the material has considerably less resisting power than it would have to a slowly and gradually applied stress. Yet the time occupied by most machines in making an experiment is so considerable that no approximation towards shock is ever reached.

In making a large number of steel tests

for the East River Bridge, the question of the time to be occupied in making each experiment was gravely considered. The machine upon which most of the tests were made was worked by a hydraulic press actuated by hand power. In order to determine the effect of the time nine pieces of steel, one inch square and two feet long, were cut from the same rolled bar. These pieces were carefully measured and were placed in the testing machine without any preparation whatever. Three of the pieces were broken in ten minutes each, three were broken in six minutes each, and three were broken in twenty minutes each. The results obtained from these nine experiments only indicated a difference of some three or four hundred pounds, and no greater difference was observed between the test made in six minutes each, than those that were made in twenty minutes. It was inferred that on this particular grade of steel little or no difference could be attributed to the time occupied, provided

did not exceed the above maximum
d minimum limits.

As a mean of a number of tests on
rought iron, Kircaldy found that with
suddenly applied stress an ultimate
sistance of 46,500 pounds per square
ch was obtained, while with a stress
adually applied the resistance rose to
ty-seven thousand two hundred pounds.
nfortunately the report from which the
ove is quoted does not give any infor-
ation as to size or kind of specimens,
to the manner in which the suddenly
plied stress was exercised. In making
any experiments upon wrought iron
d steel the author observed the follow-
g phenomena: If the testing machine
run comparatively slowly—so slowly
at the motion of the cross head was a
tle slower than the natural flow of the
etal—the test piece yielding gradually,
ving a good elongation and reduction.
y increasing the speed of the machine
as to quicken the motion of the cross
ad to such a speed as to a little more
an keep up with the flow of the metal,

a higher breaking stress was reached, accompanied with less elongation and reduction of area. By still further increasing the speed of the cross head a point would be reached where there was still less elongation and reduction and where the breaking strain was higher than in the first instance, and lower than that observed in the second instance. It would therefore seem that for each metal there is a particular rate of flow to which, if the testing machine be carefully adjusted, the maximum resistance may be obtained. Yet, for the ordinary experiments upon a commercial product, or even for the purpose of comparing material with specifications, the time occupied in making the experiment may be considered as comparatively of slight moment, provided it be kept within the limits of from five to twenty minutes for each experiment.

Tests in tension require the observation of five points:

First, *the elastic limit.*
Second, *the maximum strength.*
Third, *the ultimate strength.*

FOURTH, *the elongation.*
FIFTH, *the reduction of area.*

In order of importance, as well as in order of occurrence, the elastic limit possesses by far the greatest interest to the engineer and the investigator. The elastic limit, as usually understood, is that point at which the metal, under the influence of the stress to which it is subjected, takes the first appreciable set. In the previous autographic diagrams it will be observed that the famous principle, known as "Hook's law," that the strain produced in the piece was proportional to the stress causing it is certainly true within the elastic limit. Here it will be observed that as fast as the stress on the test piece increases the pencil of the registering cylinder draws a straight line slightly inclined to the axis of Y at a constant tangent. This straight line continues until the elastic limit is reached, when, by a sudden breaking down of the molecular structure, a sharp point of inflection occurs and the curve turns rapidly towards the axis of X. Several

methods have been used for the determination of the elastic limit. Formerly it was customary to place upon the test piece two center punch marks, occupying a distance from eight to ten inches. A pair of divides were carefully set so as to exactly coincide with the center punch marks. The piece was then subjected to stresses increasing by preconcerted increments; after the application of each succeeding increment or stress was removed, the dividers applied to the center punch mark to ascertain whether the piece had indicated any permanent set. It will at once be seen that this was a comparatively rough method of making so delicate a determination. In fact, strains smaller than one hundredth of an inch are scarcely to be observed by any such method. It will be readily seen that unless the test piece is very long, so as to present a very marked increase of length at the first permanent set, the elastic limit, as determined in this way, is almost certain to be several thousand pounds too high. An improvement on

this method is obtained by the employment of micronometer screws, one or more of which are attached to the specimen, and the strain produced by the stress, together with the resulting set, if any, are recorded by measurements made with these screws. The objection to micronometer screws is two-fold. In the first place, the time occupied in making thirty or forty readings on a single test piece is so great as to make the operation of testing exceedingly tedious and wearisome; second, considerable personal equation is almost invariably introduced in ascertaining if the screw makes a fair contact.

To overcome this, electrical and frictional contacts have been devised, so as to insure that the pressure applied to the screw head, by the operator was a constant and uniform quantity. These methods have succeeded to a great degree. At the same time the micronometer screw, except in the hands of a very skilled operator, is liable to a considerable percentage of error. Again, the micronometer

screw has to be placed at such a distance from the axis of the specimen that the slightest bending or twisting on the part of the piece introduces very grave errors into the results obtained.

Several forms of vernier gauges have been contrived, which may be applied directly to the specimen, and readings of extension and set obtained with them. One of the most compact and easily managed of these may be seen in Fig. 18.

Determinations of elastic limit, either by the micronometer or vernier gauge, generally give results which are five to ten per cent. lower than those obtained by the use of dividers and center punch marks. Prof. Thurston has shown that intermittent applications of stress to a test piece, especially at or near the elastic limit, tends to raise that quantity higher and higher. The author has therefore become accustomed to make determinations of the elastic limit, simply by applying gradually increasing increments of stress to the bar, and reading the vernier gauge at the moment when the rising of the

beam indicated that the requisite stress had been reached. So long as the increments of strain are proportional to the increments of stress, it is assumed that the strain on the piece is within the elastic limit. The moment, however, that the strain becomes disproportionate to the increment of stress, it is assumed that the limit has been passed.

Another method of very rapidly determining the limit in a testing machine worked by screws, is obtained by carefully regulating the speed of the machine with reference to the motion of the poises along the beam, and watching the motion of the beam itself. As an example in the machine used in the Department of Tests and Experiments, the multiplication between the end of the beam and the platform of the machine is 24,000. That is, in order for the platform to move downwards one inch, the end of the beam would have to move 24,000 inches. If the cross head of the testing machine be carefully driven by the screws, so as to apply the stress to the piece, no faster

than the poise travels out along the beam, the moment that the elastic limit is reached and the piece under the application of the stress suddenly elongates, the beam will quickly drop to the bottom of its surrounding guard, and remain there stationary for a few moments, until the motion of the cross head catches up to the flow of the metal in the test-piece. Experiments on test pieces of various kinds have shown that this method of obtaining the elastic limit is fully as accurate as that by means of either the micronometer screw or the vernier gauge. It, however, does not give the amount of elongation that the test piece has undergone, and so is comparatively useless in those investigations requiring that elongation, for the purpose of calculating the modulus of elasticity. The observations on the elastic limit are by far the most important as furnishing data for the guidance of the engineer and the architect in construction, for it is now a well-established fact that if material is never strained to a point approaching the elas-

tic limit, it is safe for an indefinite life; consequently, the chief point to be observed in making experiments on materials is the careful determination of the elastic limit and the modulus of elasticity.

THE MAXIMUM STRENGTH.

After passing the elastic limit, the curve on the cross-section paper proceeds forwards gradually, inclining more and more towards the axis of X, and assuming a general parabolic form. After proceeding in this way for some time, the maximum strength of the material is reached. At this point the rapidity of the application of the stress is equaled by the flow of the molecules in the test piece. For a few moments the curve becomes approximately parallel to the axis of X, and the entire work done by the testing machine is consumed in moving the molecules from the outside of the test bar towards its interior. In a few moments, however, this rapid movement of the molecules is attended by contrac-

tion in the size of the bar. As the result of this contraction there are a less number of molecules in the cross section to resist the force applied to the test piece, consequently the stress begins to decrease, the flow of the molecules becomes more and more rapid, until at last the rupture of the piece is obtained. In previous experiments very little account has been made of the difference between the maximum and the ultimate stresses to which the test piece in tension is subjected. In fact, excepting in those machines in which the weighing is done automatically, this difference is hardly perceptible, and even when it is perceptible, it is difficult by hand to remove the weights from the testing machine with sufficient precision to catch accurately the ultimate stress at which the piece is ruptured. By means, however, of the autographic testing machine the entire behavior of the test piece may be readily observed. Generally the ultimate and the maximum are regarded as almost one and the same quantity. In steel and wrought

iron it will be seen from the foregoing diagrams that they are exceedingly different. Whereas, in experiments made on brittle and hard materials, having little or no ductility, these quantities are so nearly the same as not to require any special mention.

DEFORMATION.

Upon all materials of a ductile character the effect of the stress is to produce more or less deformation in the size and the shape of the piece. In tension specimens the piece is elongated considerably, and the point at which the fracture occurs is by the flow of the metal drawn down more or less to a conical point. Pieces that are subjected to compression are shortened in length, and by a reversed process are bulged out into a sort of a barrel shape form; while in transverse stress the piece is bent into a U-shaped form. In tension pieces the amount of elongation and the amount of contraction of area are regarded as exceedingly good indications of the value of the material for structural purposes.

ELEVATION OF THE ULTIMATE AND THE ELASTIC LIMIT.

It was first observed by Prof. R. H. Thurston and Commander L. A. Beardsley, U. S. N., independently, that if a ductile material be subjected to a stress beyond the elastic limit, but not beyond its ultimate resistance and then allowed to rest for a definite period of time, a considerable increase of elastic limit and the ultimate resistance may be detected. In other words, the application of stress and the subsequent rest increases the resistance of the material. Table No. 4 gives a number of experiments made by the U. S. Board on specimens of various sizes. Each specimen was subjected to two tests, and the length of time allowed between first and second tests is given in the table. It will thus be seen from the inspection of this table that the ultimate resistance was very largely increased by allowing the piece to rest more or less between the experiments. The cause of this may perhaps be explained by the theory that, as soon as the elastic limit

TABLE 4.

Size of bar.	Strength in Pounds per Square Inch.		Interval between	Gain in Strength
	1st Test.	2d Test.	Tests.	Pr. ct.
1 1/4	50,825	51.351	1 minute	1
1 7/8	48,809	49,110	1 minute	0.6
1 1/4	49,877	50,614	3 minutes	1.5
1 3/8	49,024	49,637	3 minutes	1.3
1 1/2	49,865	50,388	3 minutes	1.0
7/8	49,345	49,993	1 hour	1.3
7/8	49,358	50,219	2 hours	1.7
7/8	49,459	51,362	3 hours	3.8
7/8	49,484	51,546	4 hours	4.2
7/8	49,401	51,561	5 hours	4.3
7/8	49,206	51,996	6 hours	5.6
7/8	50,257	52,886	7 hours	5
7/8	50,013	52,572	8 hours	5
1	51,536	60,631	3 days	17.6
1 1/4	49,935	58,251	3 days	17
1	49,962	56,207	3 days	12.5
1 3/8	49,175	57,635	3 days	17 2
1 1/2	49.267	58,049	3 days	17.8
1 5/8	50,143	58,136	3 days	14.1
1 3/4	49,266	57,263	3 days	16.2
1 3/4	49,438	57,991	3 days	17.3
1 7/8	48,587	54,655	3 days	12.6
2	48,597	57,124	3 days	17.5
1 3/8	48,853	57.443	8 days	17.6
1 1/2	50,015	59,047	8 days	18
1 1/8	50.474	59,864	18 days	18.6
1 1/8	50,178	58,314	18 days	16.1
1 1/8	50,165	54,749	18 days	9
1 5/8	49,676	59,184	25 days	19.1
1 5/8	49,867	55,949	42 days	12.2

TABLE 4—(Continued).

Size of bar.	Strength in Pounds per Square Inch.		Interval between	Gain in Strength
	1st Test.	2d Test.	Tests.	Pr. ct.
1	51,128	60,902	6 months	19.1
1 1/8	50,530	59,626	6 months	18.
1 1/4	49,101	57,877	6 months	17.8
1 3/8	48,819	56,885	6 months	16.6
1 1/2	51,888	57,188	6 months	10.3
1 5/8	49,144	58,188	6 months	18.3
1 3/4	48,792	57,403	6 months	17.2
1 7/8	49,370	58,880	6 months	19.4
2 1/4	49,250	58,020	6 months	17.7
2 1/2	47,871	58,976	6 months	22.6
2 3/4	46,702	54,458	6 months	16.6
3	47,665	57,250	6 months	20

ABSTRACT FROM DETAIL OF TESTS.

	Per cent.		Tests.
Average gain in less than 1 hour.	1.1	..	5
Average gain in less than 8 and over 1 hour.....	3.8	..	8
Average gain in 3 days	16.2	..	10
Average gain in 8 days.....	17.8	..	2
Average gain in over 8 days and less than 43 days.....	15.3	..	5
Average gain in 6 months.....	17.9	..	12

is reached and the metal begins to flow, the molecules, subjected to the force of the stresses, take up new positions with reference to each other. As long as this stress is continued the moving molecules have acquired a certain momentum.. If, however, the stress be removed and the piece be left to itself, the molecules come to rest and assume new positions with reference to each other, and the forces of cohesion again come into play and give the piece an increase of tenacity.

EFFECT OF MECHANICAL TREATMENT.

The amount of work that is done upon a piece of iron or steel, whether under the hammer or in the rolling mill, plays an important part in the quality of the material. It has been found by experiment that bars of ductile material, which are apparently precisely alike in every respect, except in area of section, do not give the same elastic or ultimate resistance per square inch. Other things being equal, bars of the smallest cross section give the greatest intensity of ulti-

TABLE No. 5.

Diameter of bar.	Tensile Strength.	Elastic Limit.	Diameter of bar.	Tensile Strength.	Elastic Limit.	Diameter of bar.	Tensile Strength.	Elastic Limit.
"	56,334	33,921	1 1/8 "	54,114	——	2 1/4 "	51,530	——
"	55,253	34,784	"	57,789	34,160	"	49,290	32,163
"	53,893	32,712	1 1/4 "	57,874	——	"	48,898	——
"	53,247	32,520	"	54,410	31,354	"	46,866	28,241
"	53,752	——	"	53,846	36,573	2 1/2 "	48,475	28,932
"	52,970	32,075	"	55,018	34,283	"	47,428	29,941
"	53,022	——	"	53,264	——	"	47,344	29,758
"	50,040	30,730	"	53,151	35,323	2 3/4 "	46,446	26,383
1 3/8 "	58,926	37,548	"	51,509	20,404	3.0 "	47,761	26,400
"	58,021	32,152	"	50,395	36,254	3 1/4 "	47,014	24,591
"	54,949	31,030	"	50,547	35,954	3 1/2 "	47,000	24,961
"	54,277	33,622	"	49,816	31,214	3 3/4 "	46,667	23,636
"	52,733	34,606	"	50,129	32,271	4.0 "	46,322	23,430
"	53,557	33,650	1 1/8 "	56,577	——			
"	52,537	34,469						

mate resistance. Table 5 from the report of the U. S. Board to test iron and steel, gives a very complete exposition of the differences in various sized round iron bars.

The following experiments given in Table No. 7 were made at the Cambria Iron Co. during the investigation of the steel for the East River Bridge, to determine the difference between large and small specimens of the same steel. From several blows of steel, containing varying proportions of carbon, three different sized pieces were rolled. One piece was rolled to be two inches square, a second piece was rolled one inch thick and six inches wide, and the third piece was rolled one inch square. The pieces two inches square were set on a planer and two pieces cut out of them. One piece, marked C, in the accompanying table, was cut directly from the center, while a second piece, marked D, was cut from the side. It will thus be seen that the piece C came directly from the center of the large bar, and was taken from the spot where it had

TABLE NO. 6.—RECTANGULAR BARS.

Number.	Kind of Iron.	Size of Bar.	Stress in Lbs. per Square Inch.	
			Elastic Limit.	Ultimate.
1	Single Refined.	3×1 inches.	29,000	52,470
2	Double "	3×1 "	31,000	53,550
3	Single "	3×1¼ "	27,330	50,410
4	Double "	3×1¼ "	27,170	50,920
5	Single "	3×1 "	28,330	48,700
6	Double "	3×1 "	29,170	51,370
7	Single "	5×1¼ "	24,880	49,240
8	Double "	5×1¼ "	27,170	51,010

TABLE No. 7.

Progress No.	Blow No.	Bar Section.	Specimen. L′	Specimen. D″	Specimen. □″	E. Lim. lbs. □″	Ult. St. lbs. □″	Elong. %	Reduc %	C.
A.....	98190	6″×1	1	1×1	1	46000	81000	21	57.75	20.5
B.....	"	"	"	1×.970	.970	50515	82744	20	57.99	
C.....	"	2′×2	"	.980×980	.960	44792	79166	25	58.51	
D.....	"	"	"	980×.612	.600	46647	79966	25	52.42	
Direct...	"	1×1	"	1.002×1.002	1.004	50797	80677	16.5	85.43	
A.....	98204	6×1	"	1.003×.998	1.001	44955	76423	21.75	56.19	15
B.....	"	"	"	1×1.006	1.006	46223	76451	21.75	48.43	
C.....	"	2×2	"	1.007×.990	.997	44133	76981	23	63.39	
D.....	"	"	"	.998×.605	.605	41322	75207	24	39.67	
Direct...	"	1×1	"	1.002×.998	1.000	42000	69250	20	50.30	
" ...	"	"	"	1.×1.	1.	43000	69000	22.2	71.23	
A.....	98231	6×1	"	1.005×.990	.995	43216	72361	24.25	40.14	18
B.....	"	"	"	1.020×.995	1.015	43352	72660	23.	42 37	
C.....	"	2×2	"	1.005×1.005	1.010	42079	70544	27.	53.48	
D.....	"	"	"	1.005×.598	.598	41807	72324	23.	57.41	
Direct...	"	1×1	"	1×1	1.000	43000	72000	21.	71.91	

been subjected to the least possible amount of mechanical work, and had no rolled skin on it. The piece D came from the side of the bar, and had been subjected to a trifle more mechanical work, and had one surface of rolled skin. The 6 × 1-inch bar was cut into two parts, marked respectively A and B. By cutting from the side of the bar one piece, marked B, consequently had three surfaces of rolled skin, while A being cut next to it had only two surfaces of rolled skin. The bars marked direct from the rolls were rolled to one inch square, and had rolled skin on all four sides.

Table No. 8 gives a series of comparative tests between specimens as usually sent to the testing machine, and pieces cut from the same grade of steel after having undergone rolling into structural shapes. Those marked "1 × 1" were test pieces of steel broken at the Cambria Iron Co's. works in Johnstown. While the pieces marked as having been cut from various shapes were test pieces of channels, beams and flats of the same blow, num-

TABLE No 8.

Blow No.	Bar Section.	Specimen. L	D″	[]″	E. Lim. lbs. []″	Ult. St. lbs. []″	Elong. %	Reduc. %	M. Elas. lbs. []″	C.
			1.002							
93709	1″×1″	1	1.002	1.004	49004	74203	22.	68.60	28871000	18
	3½×½		1.512							
"	flat	"	.483	.730	52192	75573	23.	54.38	31111000	18
			1.000							
93711	1″×1″	"	1.000	1.000	51000	77500	21.	73.95	29411000	23
			1.754							
"	6″ channel C	"	.447	.784	49489	75893	14.	64.92	29663000	23
			1.385							
"	" F	"	.336	.507	53254	78895	19.	59.57	26627000	23
			1.766							
"	" F	"	.436	.770	51948	77922	20.	51.66	29514000	23
			.980							
93854	1″×1″	"	.980	.960	49200	76780	18.	72.6	31049000	21
	1½″×$\frac{9}{16}$″		1.455							
"	flat	"	.565	.822	55960	80280	22.4	64.23	29290000	21
			.990							
93921	1″×1″	"	.990	.980	58058	82899	20.	77.23	30300000	19

bered as each of the preceding pieces, but after each steel had been rolled into the desired shapes, the letters "C" and "F" denoting that the piece was cut from the center or flange of the bar.

Another curious fact observed during making these steel tests for the East River Bridge was the fact that the time which elapsed between the rolling of the bar and the experiment in the testing machine had a considerable effect upon the amount of reduction and elongation obtained. Bars which were placed in a testing machine as soon as they were cold were generally found to give a reduction and elongation of not over eighteen to twenty per cent. for elongation, and not over twenty-five to thirty-five of reduction; whereas test pieces cut from the same bar, after having been allowed to lie quietly for some weeks, gave an elongation of from twenty to thirty per cent. and a reduction of from forty to sixty per cent. It would seem that the molecular condition of the bar just from the rolls is exceedingly unsettled,

and if the bar be allowed to remain quietly for some time, a process analogous perhaps to that of crystallization takes place, and the molecules have time to arrange themselves in more accommodating positions so as to present a great accommodation to the stresses applied by the testing machine.

UNIFORM SIZE OF TEST PIECE.

It is obvious that some agreement with reference to the standard size for test pieces which is extremely desirable. At the present time experimenters all over this country and Europe are constantly making experiments upon a great variety of materials, and collecting a vast amount of data which can be only partly used, from the fact that the pieces experimented upon are so diverse in character, in chemical constitution, in size, and in the shapes from which they are cut, as to render comparison of various results almost an impossibility. The adoption by investigators of some system regarding the size and dimension of the

pieces to be used for experimenting would therefore seem to be a necessity. The following standard sizes, as illustrated in Fig. 30, having been found advantageous by the author, are suggested, not by any means as absolute and unvaried standards, but simply as one step towards the desired end.

For making experiments on steel and iron intended to fulfill bridge and railway specifications pieces direct from the

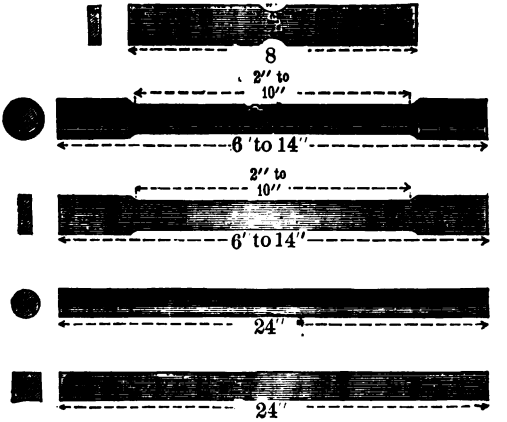


Fig. 30.

rolls may be used, as indicated in the first two samples.

For sample pieces of squares and rounds, pieces twenty-four inches long may be cut directly from the bar, having as nearly as may be one square inch of cross section. In squares this of course simply means a bar rolled one inch square, while in rounds the piece should be one and one-eighth inch in diameter. Similar observation will apply to flats and boiler plates. In the case of boiler plates, strips should be cut off having a length of twenty-four inches and having, as near as possible, widths so as to give one-fourth, one-half, three-fourths and one inch, or one square inch of cross section. Rounds, squares or flats which cannot readily be obtained in lengths of twenty-four inches, pieces may be prepared, as shown in the second two samples of the above cut. Here the pieces are from sixteen to twenty inches in length, having the center part, for a distance of ten inches, planed or turned so as to give a reduced section. In order

to break a piece of uniform size, so as to have the fracture occur exterior to the jaws of the machine, it is necessary to have the test piece sufficiently long, so that the crushing or indenting occasioned by the jaws may be distributed over quite a large area of the test piece, thereby avoiding any danger of crushing or cutting into the piece itself, so as to cause a fracture to occur inside of the jaw. In order to secure this it is essential to have a piece which is sufficiently long so as to present the required length between the jaws and give an additional quality to be placed between the gripping surfaces. In order to be certain that no crushing or indenting action occurs, it has been found by experiment best to have at least ten times as much surface in the jaws of the testing machine as there are inches in the cross section in the piece to be tested. If, however, the piece is by machine work so reduced in the center as to present a less cross section than is obtained between the jaws of the machine, this indenting action is

entirely avoided, and samples which cannot be obtained in lengths of twenty-four inches or more, may be prepared as above shown. The last figure in the cut indicates the shape of boiler plate test pieces which has previously been used as a standard size by the Government Inspectors of Steam Boilers. The piece is prepared very simply by cutting a strip from a boiler plate and planing or milling a semicircular groove directly in the center of the piece. While it may frequently be necessary to make experiments on pieces of this shape, they are, as has readily been seen from the foregoing experiments, much to be avoided. There is no opportunity for measuring the elastic limit of the piece, as there is no uniform section upon which to take it; also the grooved section of the piece very largely increases the ultimate strength of the material, at the same time decreasing the amount of reduction and entirely precluding the possibility of any stretch measurement. In order to obtain an accurate determination of the elastic limit with a

fair estimate of the ultimate strength, elongation and reduction of a material, a length of at least six inches is necessary. In previous experiments it has generally been customary to use a length of eight inches, from the fact that most testing machines have been built of so small capacity that longer pieces were not conveniently handled. This length of eight inches is, however, unfortunate for many reasons. It verges so closely upon the limiting size of the test as to at last raise the question of the accuracy of the result. All of the measurements made for determining the elastic limit and modulus of elasticity have to be reduced to decimals of the length of the test piece, involving laborious calculation for each reading of the micronometer or vernier gauge. The length of ten inches now proposed as a standard of size of test piece will avoid all computations of this kind, for every reading thus being made in inches, is made in per cent. of the length of the test piece.

Furthermore, the length of ten inches

corresponds to two hundred and fifty millimeters, approximately the length of test piece commonly used abroad.

EFFECTS OF CHEMICAL CONSTITUTION.

The resistance of wrought iron to tension varies very marked with its chemical constitution. At present it is quite uncertain to what extent foreign elements in the iron affect its quality.

Variations in the amount of phosphorus and sulphur in wrought iron play a very important part in its physical characteristics, and cannot be too carefully considered in presenting an opinion of the value of the material for structural use.

In steel the effect of variations in chemical constitution is far more marked than it is in the case of iron. The elements, phosphorus, silicon, manganese, carbon and sulphur, all enter into the constitution of most steels in small proportions. A very slight variation in any one of these may make a very marked difference in the quality and value of the steel. The elements phosphorus, silicon,

manganese and carbon have been termed by Dr. Dudley as hardening elements, inasmuch as each one of them is capable of conveying to the steel a greater or less degree of hardness. Dr. Dudley, in some experiments presented to the American Institute of Mining Engineers, assumes the hardening effect of phosphorus, silicon, manganese and carbon to be in proportion to the numbers three, five, seven and a-half and fifteen, and reckons the sum of their effects in what he very aptly terms "phosphorus units."

Dr. Dudley concludes that the sum of all these above constituents reckoned in phosphorus units should not exceed thirty to thirty-two units in steels intended for rails. The above figures, thirty-one units, are obtained by adding together the phosphorus percentage, half the per cent. of silicon, one-third that of carbon and one-fifth of manganese. Taken singly, the limit of phosphorus should be placed at $\frac{1}{10}$ of one per cent.; silicon at $\frac{4}{100}$ of a per cent.; manganese at $\frac{3}{10}$ to $\frac{4}{10}$ of a per cent. And carbon from $\frac{25}{100}$

TABLE 9.—CHEMICAL ANALYSES OF INGOT IRONS AND STEELS.

ARRANGED ACCORDING TO PER CENT. OF CARBON.

Number.	Carbon.			Sulphur.	Phosphorus.	Silicon.	Manganese.
	Total.	Combined.	Graphitic.				
1	.009	——	——	.009	.084	.163	.020
2	.057	.049	.003	.007	.179	.219	.063
3	.130	.116	.014	.029	.045	.011	.192
4	.234	.230	.004	trace	.039	.084	none
5	.238	——	——	.012	.034	.105	.184
6	.401	——	——	.006	.032	.085	.112
7	.463	——	——	.002	.020	.121	trace
8	.577	.459	.118	.026	.108	.108	.185
9	.639	.627	.012	trace	.007	.154	.050
10	.691	.675	.016	.028	.065	.028	.459
11	.756	.744	.012	.043	.104	.074	.465
12	.806	.793	013	none	.019	.172	.193
13	.873	.833	.040	trace	.015	.134	.046
14	.923	.908	.015	.002	.014	.141	.036
15	.996	.984	.008	none	.019	.157	.245
16	1.072	1.059	.013	"	.022	.162	.252
17	1.121	1.108	.013	"	.023	.206	.269
18	1.154	1.142	.012	"	.020	.204	.282
19	1.328	1.244	.084	"	.017	.246	.262

to $\frac{30}{100}$ of a per cent. Any higher proportions than the preceding make the steel too brittle for structural purposes.

The experiments in Tables 9 and 10, made by Prof. Thurston for the Committee on Chemical Research of the United States Board for testing iron and steel,

TABLE 10.

Number.	Elongation.	Elastic Limit.	Ultimate Strength.
	Per cent.	Lbs. pr. sq. in.	Lbs. pr. sq. in.
1	29.67	26,500	43,000
2	25.50	34,500	55,000
3	34.33	28,500	52,000
4	20.83	26,000	66,000
5	12.00	49,400	69,700
6	21 67	50,743	71,300
7	20.17	44,000	71,000
8	19 50	47,800	83,100
9	2.75	50,000	94,500
10	3.58	50,500	101,000
11	1.00	65,190	101,400
12	9.75	50,500	112,400
13	8.17	50,500	113,100
14	11.08	51,000	118,900
15	10.08	61,900	122,200
16	7.67	68,100	123,000
17	8.08	68,100	125,500
18	8.67	75,200	130,380
19	7.33	75,300	135,300

exhibited the chemical constitution with the corresponding physical qualities of ingot irons and steels.

A gradual increase in tensile strength and elastic limit may be observed as the proportion of carbon is increased. The quality of the metal isusually fixed by the proportion of carbon but it is also varied to a large extent by the elements, silicon and manganese, as well as by the amount of phosphorus. Prof. Thurston has given the following formula, by means of which a very fair estimate of the strength of steel may be obtained when the proportion of carbon is known: T=60,000+70,000 C. T is the tensile strength in pounds per square inch, and C is the percentage of carbon for annealed samples, and T=50,000+ 60,000 C. As illustrating this excess Prof. Thurston has made the following experiments :

TABLE 11.

Carbon.	Tensile Strength—Lbs per sq. in.	
Per cent.	By Test.	By Calculation.
0.53	79,062	81,740
0.65	93,404	88,940
0.80	99,538	98,060
0.87	106,579	102,020
1.01	109,209	110,300
1.09	116,394	113,480

The preceding examples illustrate very clearly the importance of the chemical constitution, and in all specifications for building materials, whether of iron or steel, the chemical constitution of the metal should be required by the engineer or the architect. It is very true that the knowledge of the engineer is not supposed to be that of the manufacturer, and it would be highly unreasonable for the engineer to prescribe to the manufacturer exactly what formula he should use to obtain the material wished for. At the same time a clause inserted under the

head of tests in specifications, requiring a chemical analysis of every melt of steel and frequent analyses of wrought iron, would add very largely to the amount of knowledge obtained of the material to be used, to say nothing of the immense advantage which would accrue, both to the manufacturer, to the engineer, and to the general scientific community, by a correlation between the physical tests and the chemical constituents. While the manufacturer should be allowed a wide margin of chemical constitution, it would be well in specifications, especially those designed for steel work, to prescribe limits for the elements of manganese, carbon, phosphorus and silicon, which the manufacturer should not be allowed to transcend. For it is very possible to make a steel which may come up to a liberal specification and at the time be in many respects unfit for use in a bridge or a building, and in order to avoid difficulties of this kind, limiting maximum and minimum values to the proportions of carbon, phosphorus, manganese and silicon should

be assigned in the specifications as well as the maximum and minimum values for elastic limit, tensile strength, reduction and elongation.

WORK DONE IN TESTING.

One of the most important qualities of the material is its resilience or power of resisting shock. This quality is measured by the mechanical work done during the processes of testing. Until recently this quality has been rather overlooked by engineers, but at the present time is demanding more and more attention. The mechanical work done upon a piece tested in tension is most readily obtained by the autographic method, for it is simply the area of the curve enclosed between the axis of X, the curved line given by the test of the piece and the bounding ordinate parallel to the axis of Y. It will thus be seen that the tensile strength, together with the elongation of the piece, are factors in its resilience, so that a piece very stiff and brittle, while it might have an exceeding-

ly high tensile strength, would, having very little elongation, give a very low resilience, and again, softer material having an exceedingly low tensile strength, but a very large amount of elongation, might err on the other side and give equally unfavorable results.

Practical experience has shown that the quality demanded in our bridges, roofs and other structures, is the power of resisting sudden shocks and jars due to the work to which they are subjected, and this power of resisting shock is by far the most important one. A piece of tool steel, while exceedingly strong, will, under a suddenly applied stress, snap like a piece of brittle glass, while the weaker and more resilient structural steel will, under a suddenly applied load, stretch like a piece of india-rubber and come back again to its normal position. While the amount of work done in breaking a test piece is an exceedingly valuable and important characteristic of amount of work up to the elastic limit, is by far the most valuable. And this quan-

tity may be readily calculated by taking the elongation at the elastic limit and multiplying it by half the elastic limit in pounds per square inch. Assuming Hook's Law to be true, this gives the value of the triangle included by the line whose equation is $Y = ax$, and may be assumed to be very accurately the measure of the resilience of the piece up to the elastic limit.

EFFECT OF TEMPERATURE.

As a result of a mechanical work done on the piece by a machine, and of the flowing of the molecules of the metal, the piece gradually becomes warm, so that if the testing machine is very rapidly worked, and the bar is comparatively small, the ends near the fracture may at the end of the experiment become so hot as to be most unbearable to the hand. Probably this elevation of the temperature during the experiment has some effect upon the ultimate resistance, for unquestionably an elevation of the temperature causes the flow of the metal to take

place with slightly increased facility. Yet in ordinary experiments this elevation of the temperature is so slight as to produce no sensible effect upon the test piece. Some experimenters have gone so far as to carefully make a thermometrical measurement of the heat produced in this way. While all possible commendation should be given to accuracy and care in making observations, it seems that examinations of this kind are hardly worth the amount of expenditure and trouble that they cause.

That the variation of temperature produces some effect upon the tensile strength of iron and steel is a well understood fact.

From a recent number of the *London Engineering*, a synopsis of some German experiments is obtained. The resistance of the materials at zero centigrade is taken at 100, and that of other temperatures in the proper proportional part of that number, Table 12.

TABLE 12.

Temperature.		Fibrous Iron.	Fine Grained Iron.	Bessemer Steel.
Cent.	Fahr.			
0°	32°	100	100	100
100	212	100	100	100
200	392	95	100	100
300	572	90	97	94
500	932	38	44	34
700	1,292	16	23	18
900	1,652	6	12	9
1,000	1,832	4	7	7

Sir William Fairbairn gives the following as the results of numerous experiments made upon specimens of plate and rivet iron at different temperatures, Tables 13 and 14.

TABLE 13.—EXPERIMENTS ON PLATE IRON.

Temperature, Fahrenheit.	Breaking weight in lbs. per. sq. in.	Stress in Reference to Fibre.
0°	49,009	With.
60	40,357	Across.
60	43,406	Across.
60	50,219	With.
110	44,160	Across.
112	42,088	With.
120	40.625	With.
212	39,935	With.
212	45,680	Across.
212	49,500	With.
270	44,020	With.
340	49,968	With.
340	42,088	Across.
395	46,086	With.
Scarcely red	38,032	Across.
Dull red,	30,513	Across.

TABLE 14.—RIVET IRON.

Temper-ature. Fahr.	Breaking weight in lbs. per sq. in.	Temper-ature. Fahr.	Breaking weight in lbs. per sq. in.
−30°	63,239	250	82,174
+60	61,971	270	83,098
66	63,661	310	80,570
114	70,845	325	87,522
212	82,676	415	81,830
212	74,153	435	86,056
212	80,985	Red heat.	36,076

From these tables it will be observed that between the ordinary variation and temperature there is little or no variation of the strength of iron or steel. That many accidents occur from the breakage of railroad rails, tie rods, axles, and many other parts of our common structure during cold and frosty weather, is beyond question; but these failures must be attributed not to a decrease in actual strength of the metal, but to exterior circumstances. Under severe cold of a winter's night the road bed enveloping the track of the railway may become frozen exceedingly hard, and to the passage of the moving train present a structure which is firm and unyielding as that of the most solid granite. Thus the blow struck by the engine driver against a projecting rail end is much more severe on a cold and frosty day than it is on a warm and sunny one, so that the possible breakage of the rail under circumstances of this kind may be attributed, not to a decrease in the strength of the iron, but to exterior circumstances.

The investigator in making experiments on cast iron is obliged to exercise more care than in experiments on almost any other material. Cast iron is of such an unyielding and crystalline nature, that unless care is taken in setting the piece in the testing machine the results are almost certain to be vitiated by the presence of lateral stresses. Again, unless the piece is prepared in some manner by turning and planing at the center, so as to give a reduced section, there is great danger that the jaws of the testing machine will not grip the piece sufficiently tightly so as to avoid slipping.

If the piece should be taken direct from the sand, without any machining or planing, it becomes quite a difficult matter to get an accurate measurement upon which to calculate the area of the piece, for the outside of the specimen contains a large quantity of sand, which penetrates to a depth of one or two hundredths of an inch, so as to almost preclude the

possibility of making accurate measurements.

The effect of remelting on the strength of cast iron is well exemplified by the experiments in Tables 15 and 16.

TABLE 15.

	Lbs. per sq. in.
First melting	14000
2d "	22900
3d "	30229
4th "	35786

TABLE 16.

Time of fusion.	Lbs. per sq. in.
½ hour	17843
1 "	20127
1½ "	24387
2 "	34496

The accompanying table gives a fair average of the results to be generally obtained from tension tests on cast iron:

Good pig iron from 15,000 to 20,000 lbs. per square inch.

Tough cast iron from 18,000 to 24,000 lbs. per square inch.

Hard cast iron from 20,000 to 28,000 lbs. per square inch.

Gun-metal from 25,000 to 32,000 lbs. per square inch.

These are the averages that have been obtained from a large number of miscellaneous irons obtained from various foundries all over the country. Here and there will be found an iron that either exceeds or falls below the preceding averages, as an example of which may be mentioned a phenomenal one sent to the author to be tested by the author within the past year from the foundry of Mr. Gridley, at Warsaw, N. Y. This piece, of pig iron unrefined stood over 40,000 lbs. per square inch.

CEMENT TESTING.

Next to iron and steel, probably the materials which are most subjected to experiment, are the various cements and concretes used for all architectural purposes. Among architects and engineers it is very customary upon buying a lot of cement to take small samples from several of the barrels in each cargo, and after mixing them up and pressing them

into a mold, to break the sample by tension, and to judge of the quality of the cement by the results thus obtained.

In making cement tests the following precaution should be observed:

First, the relative quantity of cement and water should be carefully measured, preferably by weighing out the necessary amount of each.

Second, the cement and the water should be carefully and thoroughly incorporated so as to make a mixture which is perfectly uniform in every respect. This is best accomplished by placing the cement on a plate of glass, and slowly pouring the water on it while the mass is being stirred and rubbed by means of a towel.

Third, after the mixture is completed, the cement should be pressed into the mold designed to form the briquette with a perfectly steady and uniform pressure. This is best accomplished by arranging the mold so that it may be filled with cement, then subjected by means of a press

to an amount of force that can be definitely weighed.

Fourth, the length of time elapsing between the mixing of the cement and the breaking of the sample should be accurately noted.

Fifth, the temperature of the room in which the samples are kept between the mixing and the breaking, should be maintained as nearly uniform as may be, and preferably should be kept at from 60 to 70 degrees Fahrenheit.

Sixth, the fineness of the grinding of the cement should be carefully noted. It has been customary among English and American experimenters to weigh out a portion of the cement to be tested, and sift it through a sieve containing 2,500 meshes per square inch. The fineness of the cement is expressed by the per cent. of the amount which will pass through the measures of the sieve.

Seventh, the hydraulic properties of the cement are best ascertained by mixing a sample to a requisite quantity of water, and then testing it in two ways:

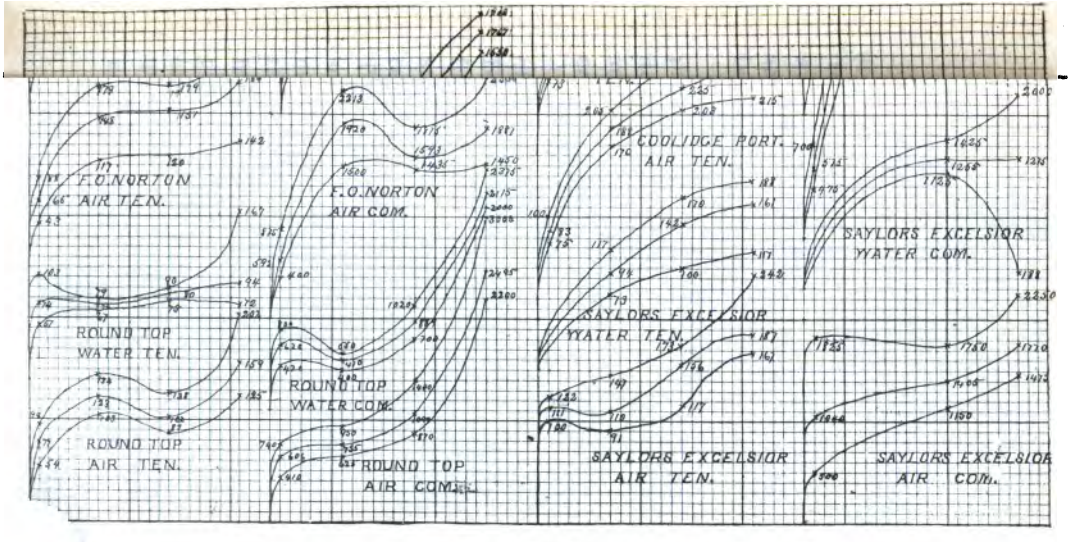

F.O.NORTON
AIR TEN.
F.O.NORTON
AIR COM.
COOLIDGE PORT.
AIR TEN.
SAYLORS EXCELSIOR
WATER COM.
ROUND TOP
WATER TEN.
ROUND TOP
WATER COM.
SAYLORS EXCELSIOR
WATER TEN.
ROUND TOP
AIR TEN.
ROUND TOP
AIR COM.
SAYLORS EXCELSIOR
AIR TEN.
SAYLORS EXCELSIOR
AIR COM.

FIG. 31.

First, by immersing it in water and seeing whether the cement does not lose its form after being subjected to the water for some time and does not show any cracks or other symptoms of disintegration.

Second, by allowing a blunt point to press upon the cement by means of a definite weight, the penetration being assumed as a measure of the setting properties of the cement.

At the commencement of the erection of the approaches to the East River Bridge, it was decided to employ cement for laying the masonry work. As a consequence of this, proposals for supplying cement were advertised for by the Bridge Trustees. A number of manufacturers sent samples in answer to this advertisement, and Fig. 31 gives a series of curves that are taken from the results obtained from these tests. All the samples here given were made by mixing 4 parts of cement with one part of water by weight. The mixture was then rammed into molds having a cross section of 3 inches, and a

uniform length of 3 inches between the enlarged ends. After the briquettes had been in the molds for 15 minutes they were removed, half the number of briquettes being placed in water, and half being retained in the air until the time for testing. After the tension test was made, the end of the broken briquette was trued up on a grindstone and tested in compression. As a consequence, on the diagram there will be seen 4 curves for each make of cement, one curve giving the tensile strength in air, one in water, one of compressive strength in air, and one of compressive strength in water. The experiments were continued till the briquette had attained an age of one month, and tests were made at intervals of 24 hours, 7 days, 14 days, 21 days and 28 days. An inspection of these curves will reveal the fact that while they vary considerably in actual strength per square inch, all the curves bear a general resemblance to each other. Each curve rising with a slight inclination to the axis of y, until the seven day test is

passed. There then occurs a point of inflection, the curve swinging towards the axis of x, in some cases even taking on a negative value, and returning towards that axis. This dropping of the curve continues until the fourteenth day is passed, when the second point of inflection occurs, the curve returns towards its former position and extends indefinitely. It would seem from these experiments that the hardening of cement is probably due to two different causes, one of which reaches the maximum about the seventh day, while the other does not come into action until after the fourteenth day. In explanation of this fact it is supposed by the author that this hardening is due to two different variations. When the cement is first mixed, the primary hardening is due to the hydration of the salts of lime and alumina by means of the water used in the mixing. This hydration reaches its maximum in intensity at about the seventh day. After that the action of the atmosphere on the cement probably causes the hydrates of

calcium and alumina to give up part of the water that is absorbed, and change to silicates and carbonates. This interchange of molecules causes a slight weakening of the cement. This weakening goes on from seven to fourteen days, until after the passage of the fourteenth day the carbonates and silicates have only regained the strength of the hydrates they have replaced, and then probably go on hardening and strengthening for an indefinite period of time.

The Table 17 gives the result of a series of tests made on cement supplied by two of the most noted Rosendale Cement Company's.

TABLE 17.

Age.	Cement A.		Cement B.	
	Tension in lbs. per sq. in.		Tension in lbs. per sq. in.	
	Air.	Water.	Air.	Water.
1 hour...	45	38	49	32
2 " ...	52	44	53	45
3 " ...	60	55	71	61
4 " ...	63	57	75	62
5 " ...	71	64	79	67
6 " ...	77	65	85	71
7 " ...	82	65	87	74
8 " ...	86	78	86	76
9 " ...	87	69	85	75
10 " ...	88	63	89	74
15 " ...	94	74	97	90
20 " ...	94	77	98	96
24 " ...	88	70	95	90
2 days...	81	72	89	86
3 " ...	91	72	91	59
4 " ...	125	69	117	68
5 " ..	155	71	115	72
6 " ...	149	83	149	83
7 " ...	103	71	111	62
14 " ..	117	94	183	86
21 " ...	148	129	149	113
1 month.	192	205	188	185
2 " .	202	199	216	220
3 " .	209	216	196	187
4 " .	201	217	140	148
5 " .	243	242	196	186

TABLE 17—(Continued).

Age.	Cement A. Tension in lbs. per sq. in.		Cement B. Tension in lbs. per sq. in.	
	Air.	Water.	Air.	Water.
6 months.	182	180	232	212
7 " .	186	296	361	210
8 " .	319	236	311	235
9 " .	225	216	209	199
10 " .	264	226	177	209
11 " .	280	245	178	187
12 " .	255	244	190	149
13 " .	263	226	174	142
14 " .	178	249	184	191
15 " .	226	213	144	176
16 " .	248	216	292	240
17 " .			203	190

These tests were made on briquettes mixed in the same manner as those in the preceding tests, and treated in the same way in every respect, excepting that they were tested at intervals of from 1 hour to 17 months.

PROOF TESTS.

The testing machine is frequently employed to make proof tests upon parts of structures to ascertain whether there may be any concealed defects either in quality of materials or in character of the workmanship. For example, in making bridge columns, eye-bars, chains and cables and the like, it is customary to test each article after the manufacture is completed by placing it in a testing machine and subjecting it to a stress which is slightly in excess of that which it is calculated to meet in the structure. Nearly all eye-bars of the best bridges are tested in this way, being subjected to a strain of about 15,000 pounds to the square inch. This is largely expected to exceed the stress to which they will be subjected in the structure, but at the same time it is not intended to quite reach the elastic limit of the bar itself, and so no injury can result therefrom. Whereas, should the bar be defective in any way, either from concealed flaws, welds, or poor material, this proof stress

will make the defect sufficiently obvious to cause the rejection of the piece. In many cases, however, it is doubtless that these proof tests have been too severe, for if the piece in question be overstrained so as to injure any of the fibers, or cause an incipient crystallization, the test, instead of insuring safety, insures the commencement of destruction.

In making proof tests the action of the piece subjected to the stress should be very carefully noted, especially to see whether there is the slightest symptom of deformation, causing, after the piece is taken from the testing machine, a permanent set in the material, signs of flaws, cracks, or other imperfections, should be carefully looked after, and any indication of weakness of any kind under proof test should be considered conclusive either for the rejection of the piece absolutely or for the continuance of further experimenting thereon.

TESTS TO DETERMINE THE VALUE OF DIFFERENT METHODS OF CONSTRUCTION.

Engineers are very rapidly ascertaining the value of the testing machine in demonstrating the best forms and the best methods to be employed in construction. To accomplish this it is of course necessary to make tests on the full-sized specimens exactly as they are to be used in the structure in question. While many experiments have been on such forms as eye-bars, columns, small plate girders and trusses, riveted joints and the like, yet the art is in its very earliest stage of infancy, so that it is almost impossible to give any rules for the guidance of experimenters in this direction, excepting the very general ones, that the pieces should be tested in a manner precisely analogous to that which they will be called upon to resist in the structure itself, and that all circumstances during the progress of the experiment should be noted with the most minute and scrupulous attention, so that an after consideration of all of the

facts thus obtained, may lead to the development of the most perfect knowledge.

The sad and disastrous failures that have occurred in various structures throughout the country during the past history of American engineering has demonstrated too completely the lack of correspondence between the physical properties of materials, as given from the data supplied by us: all test specimens and properties which have actually been developed in actual practice.

The importance, therefore, of making experiments on full-sized members is being more fully and completely realized day by day, and cannot be too strongly urged upon architects and engineers, so that it is hoped before long our country may be supplied with the requisite apparatus for testing any structures, be they small or large, in such a manner and on such a scale as to demonstrate to the world at large that America stands foremost among nations because she is foremost in her structures.

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